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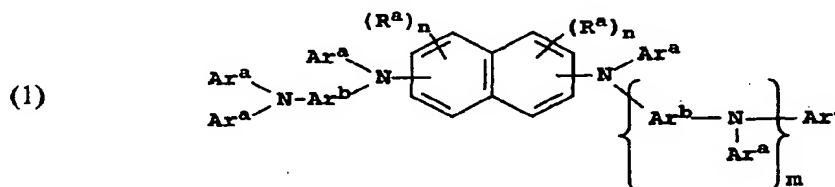
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(54) **Organic electroluminescent devices with high luminance**

(57) Disclosed is a multilayer electroluminescent device comprising a cathode, an anode, a light emitting layer (LEL) and a layer disposed between the cathode and anode containing a naphthalene compound represented by formula (1):



wherein

m is 0, 1 or 2;

each R^a is an independently selected substituent and each n is independently 0 to 3;

each Ar^a is an independently selected aromatic group; and

each Ar^b is an independently selected carbocyclic aromatic group;

provided that two ring substituents may join to form a ring.

The device provides a desired high luminance.

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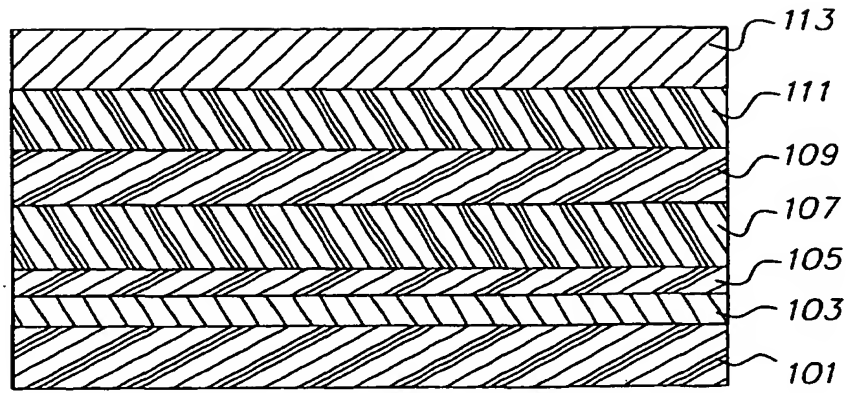


FIG. 1

Description

[0001] This invention relates to organic electroluminescent devices. More specifically, this invention relates to devices that emit light from a current-conducting organic layer and have high luminance.

[0002] While organic electroluminescent (EL) devices have been known for over two decades, their performance limitations have represented a barrier to many desirable applications. In simplest form, an organic EL device is comprised of an anode for hole injection, a cathode for electron injection, and an organic medium sandwiched between these electrodes to support charge recombination that yields emission of light. These devices are also commonly referred to as organic light-emitting diodes, or OLEDs. Representative of earlier organic EL devices are Gurnee et al U.S. Pat. No. 3,172,862, issued Mar. 9, 1965; Gurnee U.S. Pat. No. 3,173,050, issued Mar. 9, 1965; Dresner, "Double Injection Electroluminescence in Anthracene", RCA Review, Vol. 30, pp. 322-334, 1969; and Dresner U.S. Pat. No. 3,710,167, issued Jan. 9, 1973. The organic layers in these devices, usually composed of a polycyclic aromatic hydrocarbon, were very thick (much greater than 1 μm). Consequently, operating voltages were very high, often >100V.

[0003] Herein, the term "EL element" encompasses the layers between the anode and cathode. Recent organic EL devices include an organic EL element consisting of extremely thin layers (e.g. <1.0 μm) between the anode and the cathode. Reducing the thickness lowers the resistance of the organic layer and has enabled devices that operate using much lower voltage. In a basic two-layer EL device structure, described first in US 4,356,429, one organic layer of the EL element adjacent to the anode is specifically chosen to transport holes; therefore, it is referred to as the hole-transporting layer (HTL). The other organic layer is specifically chosen to transport electrons, and is referred to as the electron-transporting layer (ETL). The interface between the two layers provides an efficient site for the recombination of the injected hole/electron pairs which results in light emission.

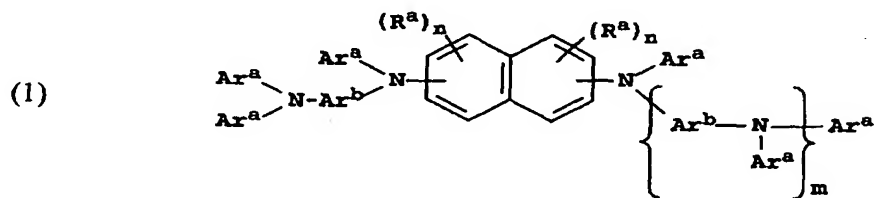
[0004] Additional layers have been proposed to further improve device performance, e.g., as described in US 4,769,292. This discloses the concept of an organic light-emitting layer (LEL) between the HTL and ETL, and the concept of a hole-injecting layer (HIL) located between the anode and the HTL.

[0005] Materials comprising porphyrinic compounds have been disclosed by Tang in US 4,356,429 for use in the HTL. Further improvements in device performance are taught in US 4,539,507, US 4,720,432, and US 5,061,569 where the hole-transporting layer utilizes an aromatic tertiary amine.

[0006] Since these early inventions, further improvements in hole-transporting and other device materials have resulted in improved device performance in attributes such as color, stability, luminance efficiency and manufacturability, e.g., as disclosed in US 5,061,569, US 5,409,783, US 5,554,450, US 5,593,788, US 5,683,823, US 5,908,581, US 5,928,802, US 6,020,078, and US 6,208,077, amongst others. EP 891,121 and EP 1,029,909 suggest the use of biphenylene and phenylene diamine derivatives to improve hole injecting and/or transporting and JP 11-273830 suggests the use of naphthyldiamine derivatives in EL elements generally.

[0007] Notwithstanding these developments, there are continuing needs for organic EL device components that will provide a desired high luminance.

[0008] The invention provides a multilayer electroluminescent device comprising a cathode, an anode, a light emitting layer (LEL) and a layer disposed between the cathode and anode containing a naphthalene compound represented by formula (1):



wherein

m is 0, 1 or 2;

each R^a is an independently selected substituent and each n is independently 0 to 3;

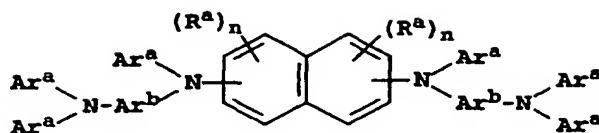
each Ar^a is an independently selected aromatic group; and

each Ar^b is an independently selected carbocyclic aromatic group;

provided that two ring substituents may join to form a ring.

[0009] The invention also provides a multilayer electroluminescent device comprising a cathode, an anode, a light emitting layer (LEL) and a layer disposed between the cathode and anode containing a naphthalene compound represented by formula (1'):

(1')



wherein

each R^a is an independently selected substituent and each n is independently 0 to 3;

each Ar^a is an independently selected aromatic group; and

each Ar^b is an independently selected carbocyclic aromatic group;

provided that two ring substituents may join to form a ring.

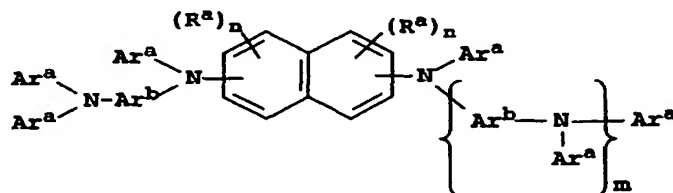
[0010] The invention also provides a naphthalene compound and an imaging device containing the EL device of the invention.

[0011] Figure 1 is a schematic diagram showing a cross-section of a first organic EL device of the invention.

[0012] Figure 2 is a schematic diagram showing across-section of a second organic EL device of the invention.

[0013] The EL device of the invention is generally as described above. In one preferred embodiment the EL device contains at least one naphthalene compound described in Formula (1).

(1)



wherein

m is 0, 1 or 2;

each R^a is an independently selected substituent and each n is independently 0 to 3;

each Ar^a is an independently selected aromatic group; and

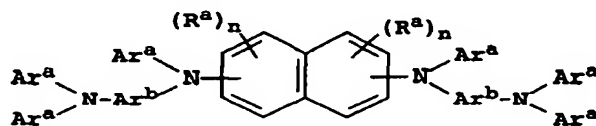
each Ar^b is an independently selected carbocyclic aromatic group;

provided that two ring substituents may join to form a ring.

[0014] Desirably, the naphthalene compound is a diaminocompound such as a 1,5-di-amino compound or a 2,6 di-amino compound. Suitable examples of groups useful as Ar^a are phenyl, tolyl, and naphthyl groups. Suitable examples of groups useful as Ar^b are phenyl and naphthyl groups.

[0015] In one preferred embodiment the EL device contains at least one naphthalene compound described in Formula (1').

(1)



wherein

each R^a is an independently selected substituent and each n is independently 0 to 3;

each Ar^a is an independently selected aromatic group; and

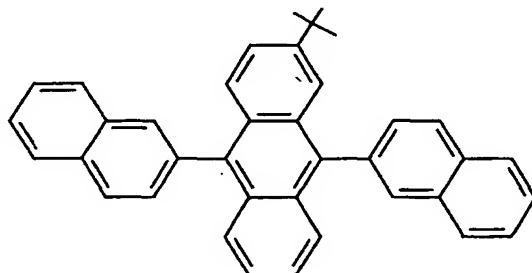
each Ar^b is an independently selected carbocyclic aromatic group;

provided that two ring substituents may join to form a ring.

[0016] Desirably, the naphthalene compound is a 1,5-di-amino compound or a 2,6 di-amino compound. Desirably at

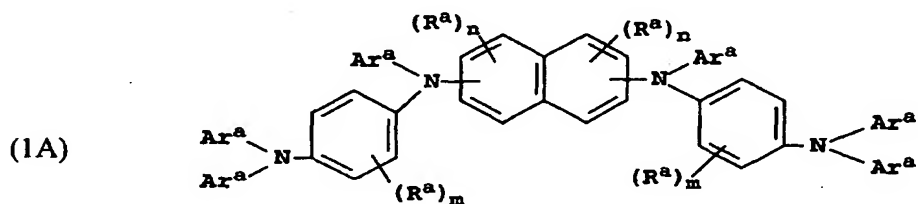
least one R^a group is an alkyl or aryl group such as a methyl, phenyl, naphthyl, or pyridyl group. Suitable examples of groups useful as Ar^b are phenyl and naphthyl groups. Suitably, at least one Ar^b is a para-substituted phenyl group.

[0017] The device is not limited as to the other materials used in the EL device. The LEL of the device typically contains a metal complex of a quinoline derivative, such as tris(8-quinolinolato)aluminum (III) (AlQ_3). Alternatively, it may contain a compound having the formula:

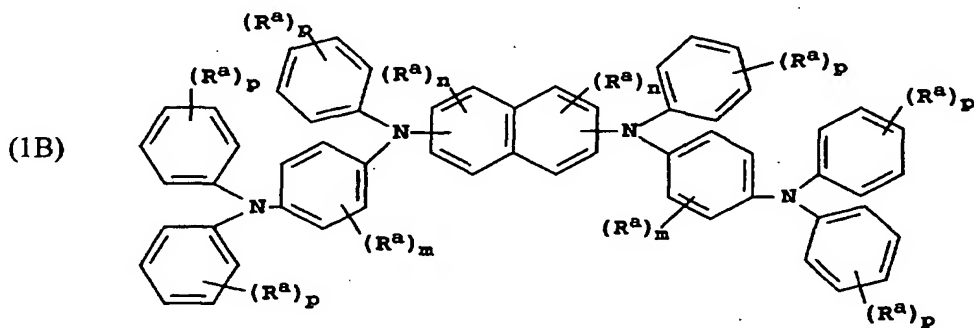


Dopants are also commonly employed in the LEL layers.

[0018] In one embodiment, the naphthalene compound useful in the device is represented by formula (1A):



wherein each Ar^a , R^a , and n are as defined for formula (1') and each m is independently 0-4. In another embodiment, the naphthalene compound is represented by formula (1B):



wherein each R^a , m , and n are as defined above and each p is independently 0-5.

[0019] The naphthalene compound is usually contained in a layer between the anode and the LEL. That layer may or may not be adjacent to the anode. In some embodiments of the invention, it is desirable that the compound is not adjacent to the LEL. The naphthalene compound useful in the invention is effective to improve the luminance efficiency of the EL device. It is believed that the naphthalene compound functions to improve hole-transporting properties of the layer in which it resides, and there is a further improvement when there is present in a layer between the anode and LEL a second compound that functions to improve hole transporting.

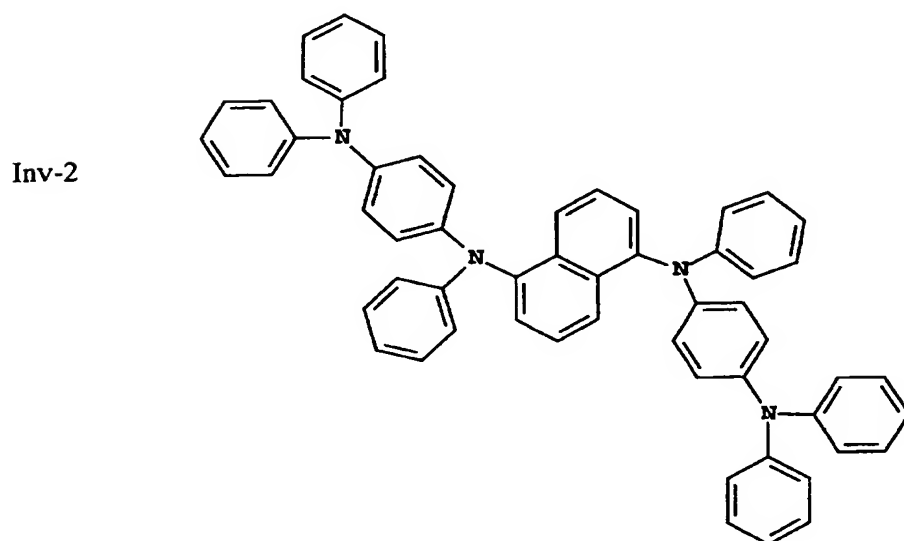
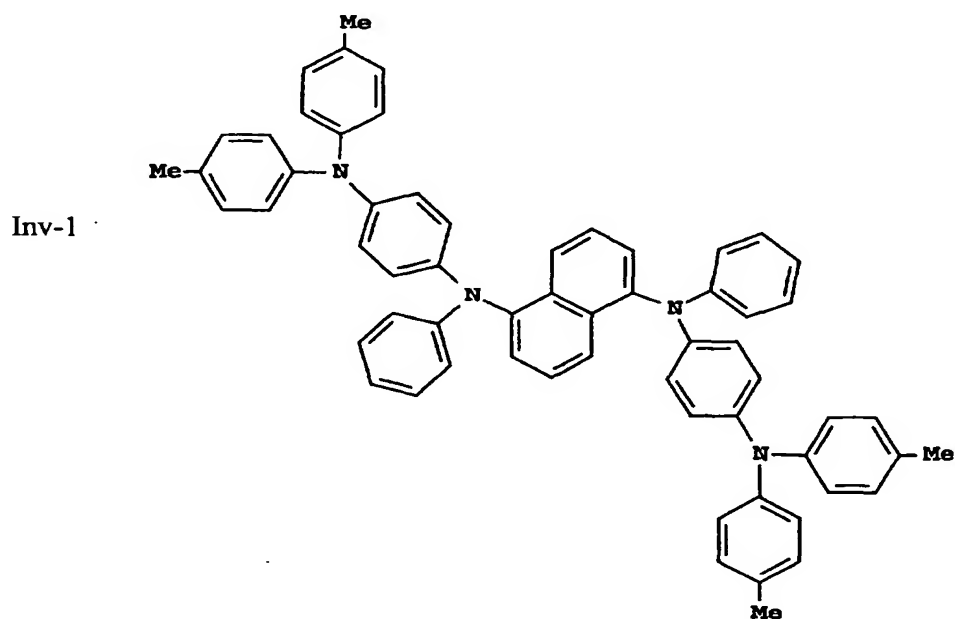
[0020] A suitable second compound is represented by formula (C):



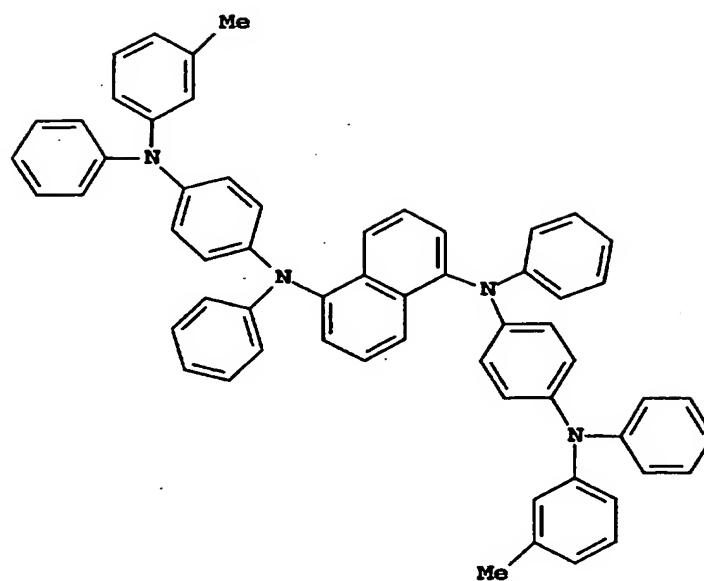
wherein Q_1 and Q_2 are independently selected aromatic tertiary amine moieties and G is a linking group or a bond. An example of the second compound is 4,4'-Bis[N-(2-naphthyl)-N-phenylamino]biphenyl. Suitably, the compound of formula C is contained in the layer adjacent to the LEL.

[0021] The EL device of the invention is desirably used as a component in a static or motion imaging device, such as a television, cell phone, DVD player or computer monitor.

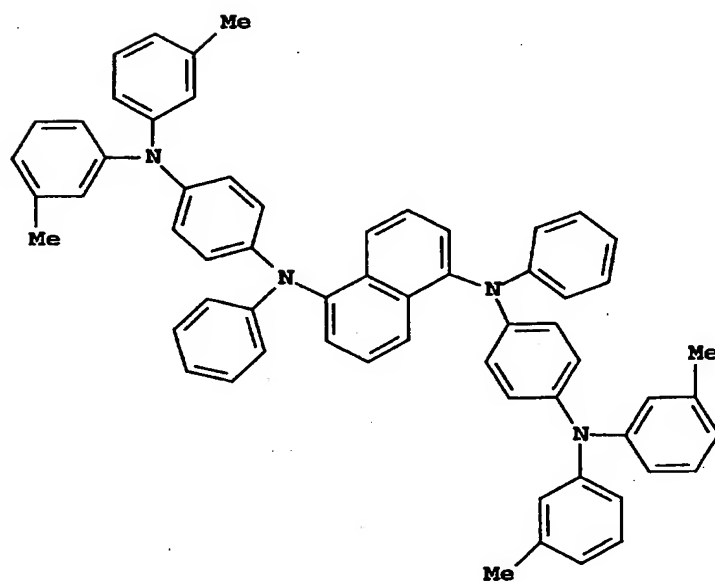
[0022] Illustrative examples of naphthalene compounds useful in the present invention are the following:

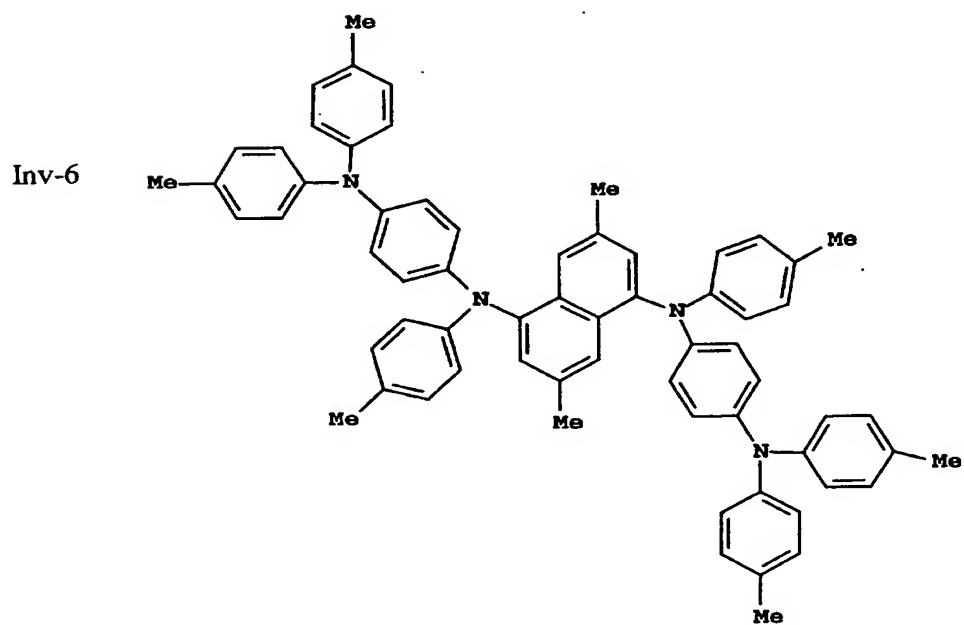
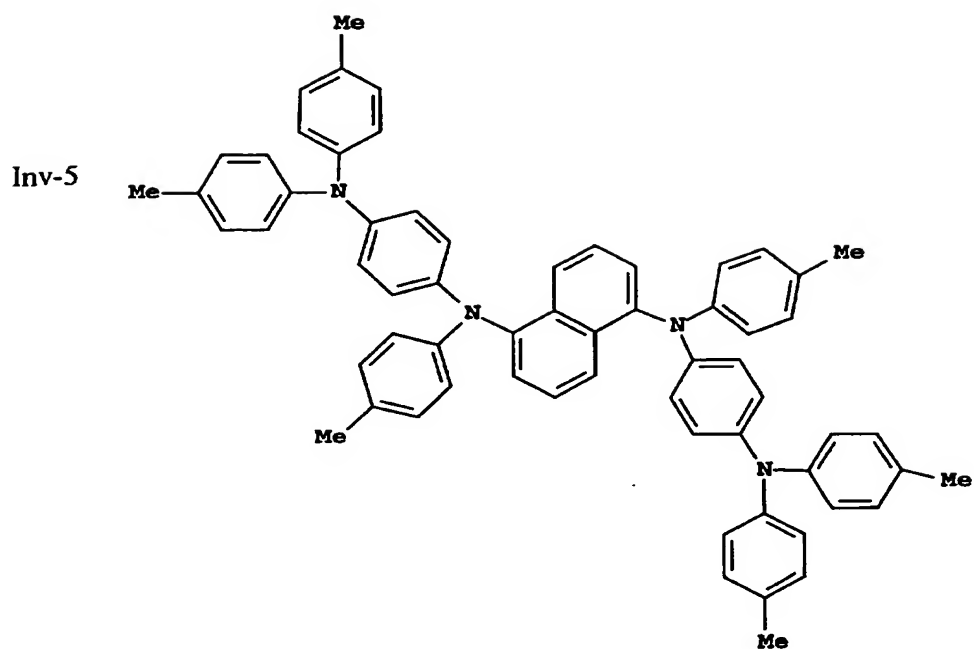


Inv-3

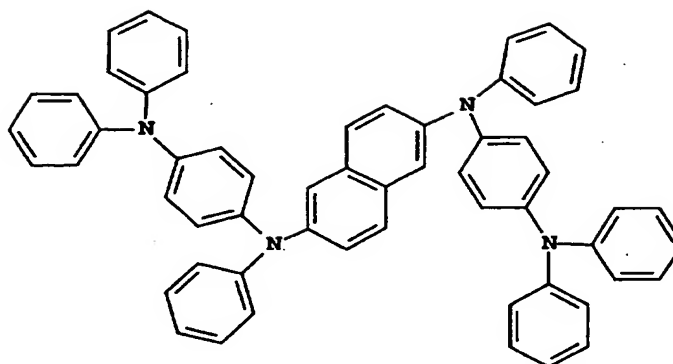


Inv-4

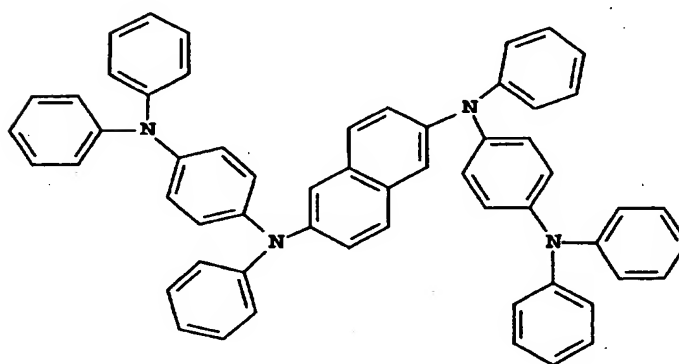




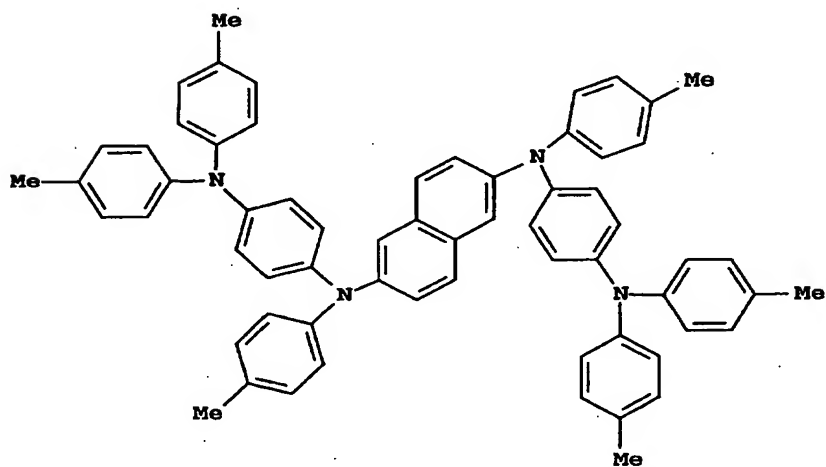
Inv-7



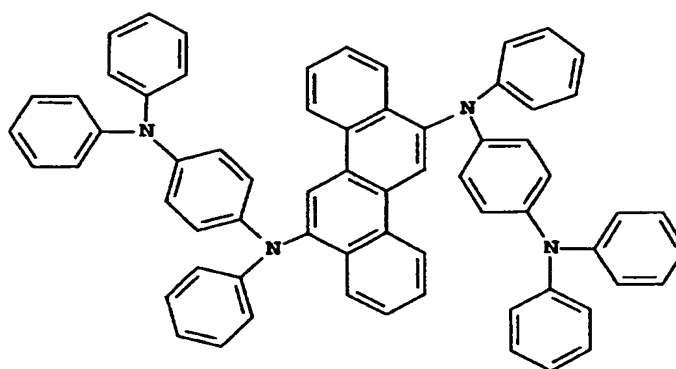
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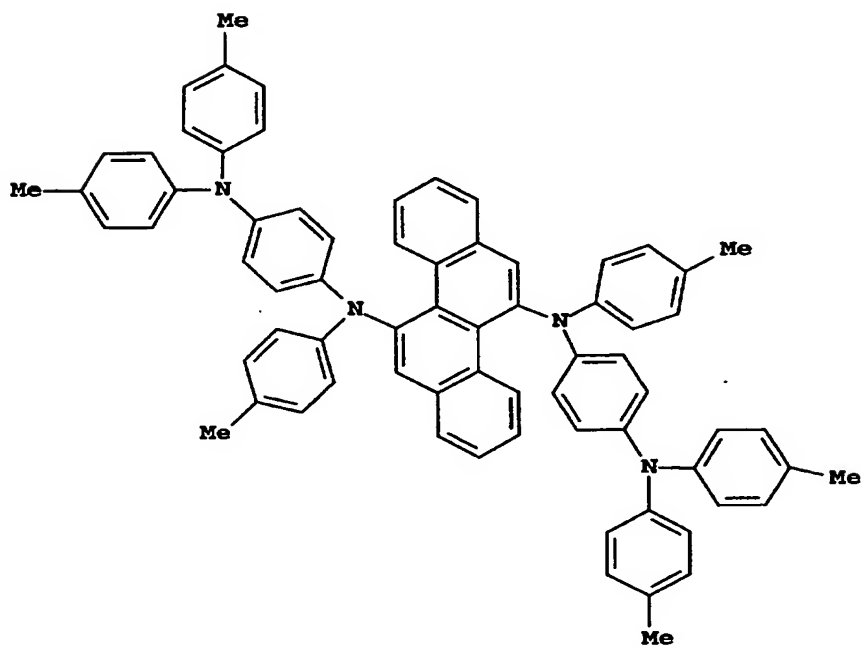
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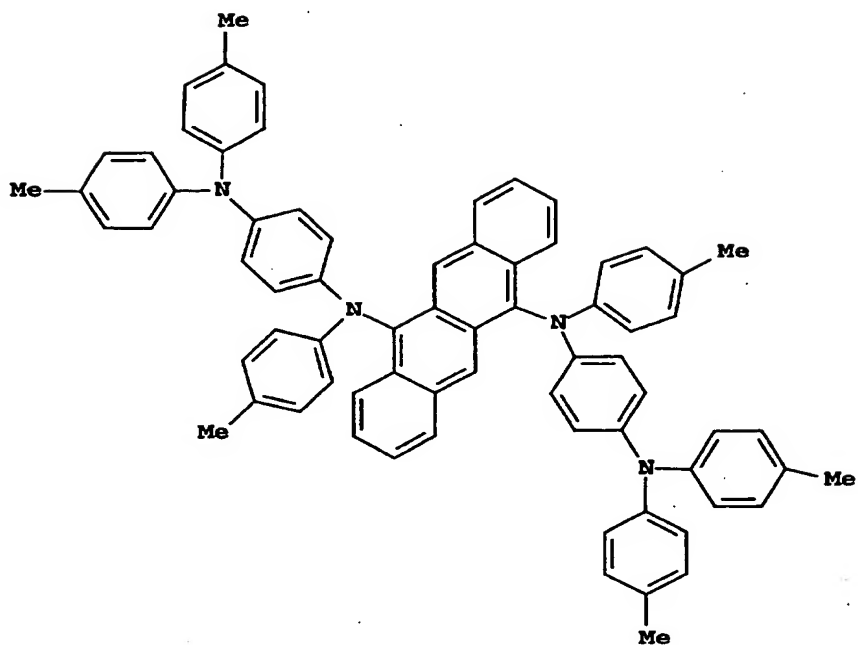
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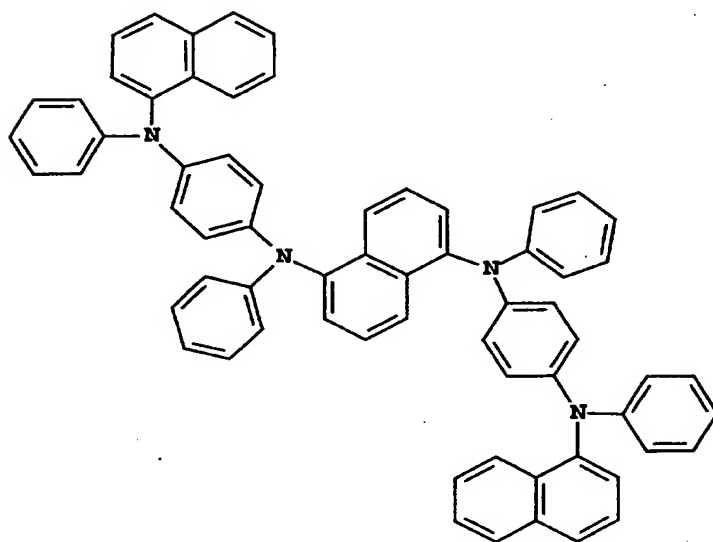
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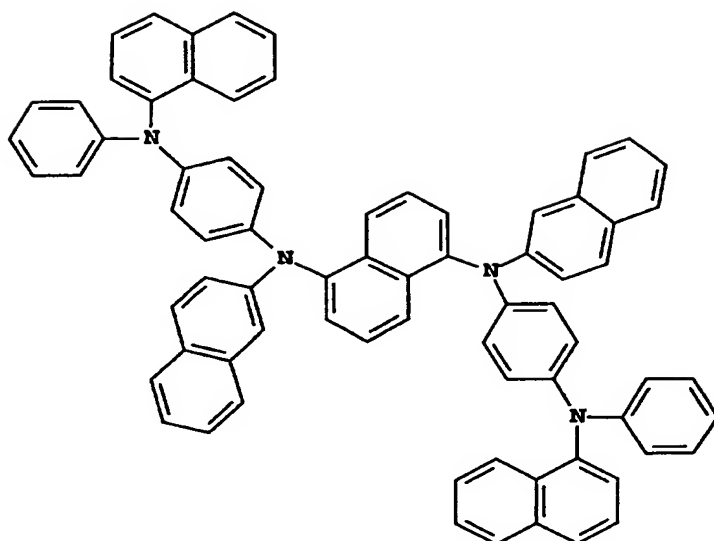
Inv-12



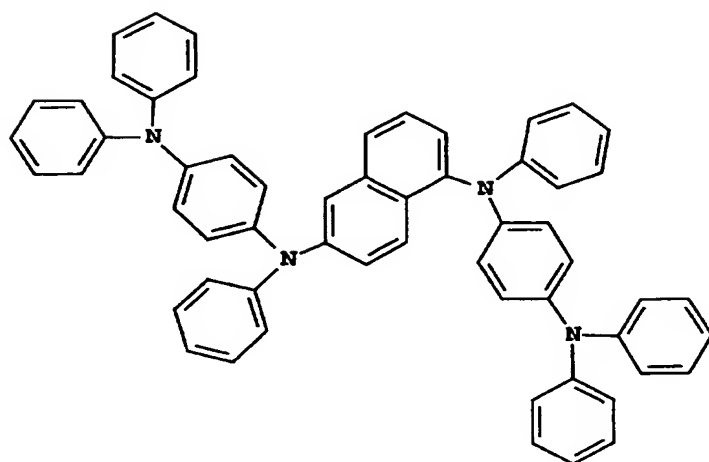
Inv-13



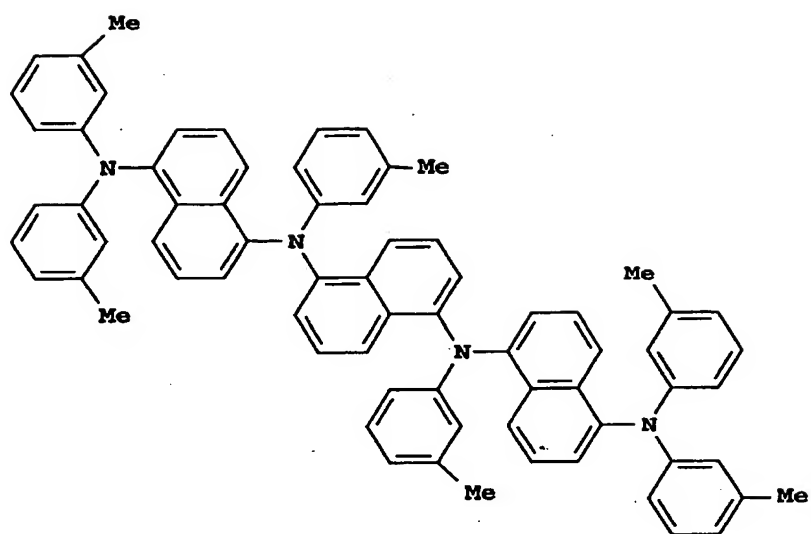
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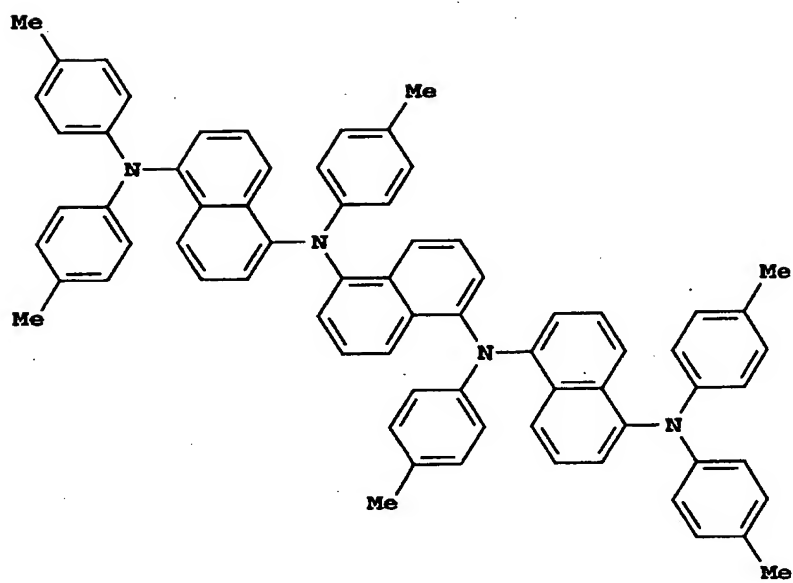
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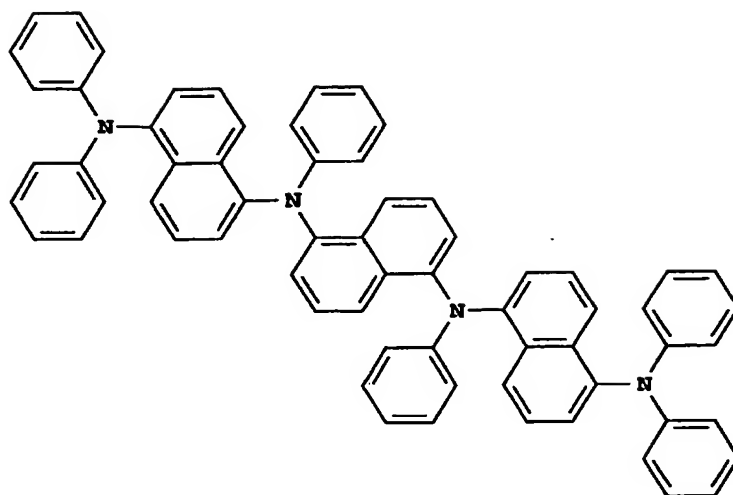
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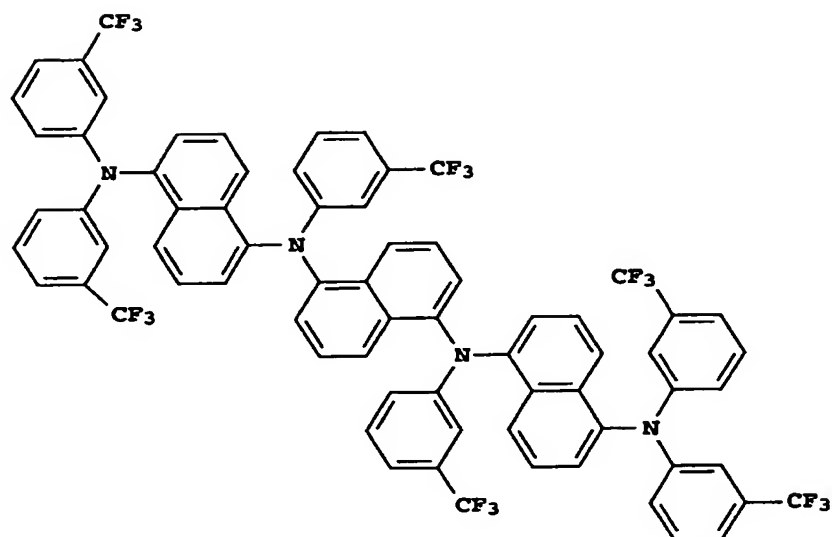
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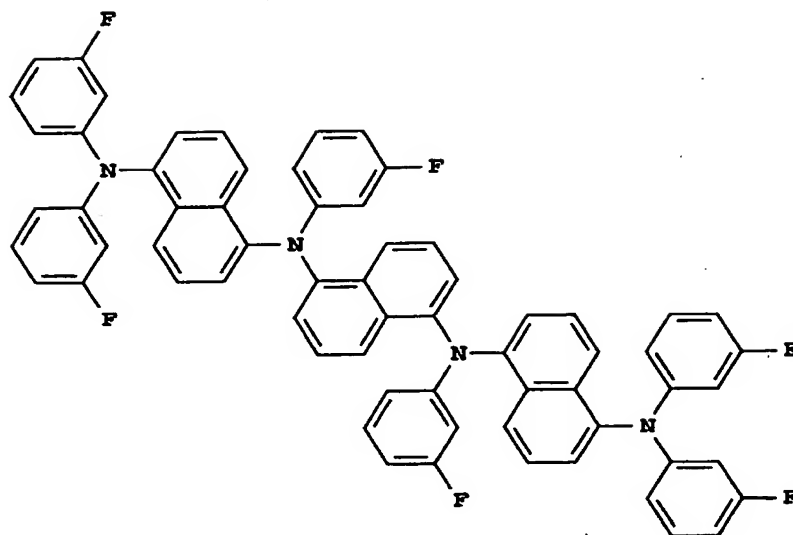
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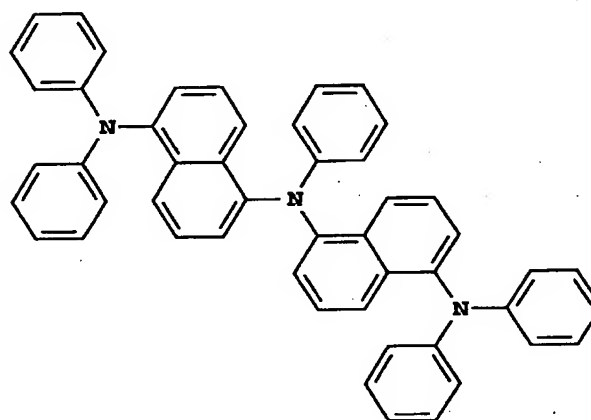
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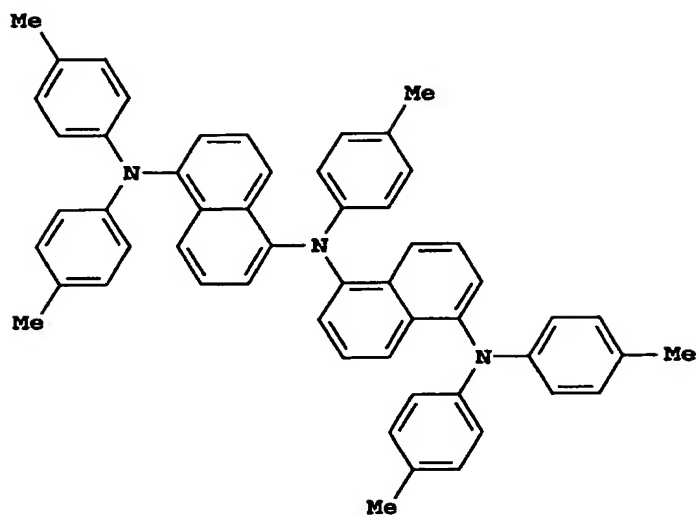
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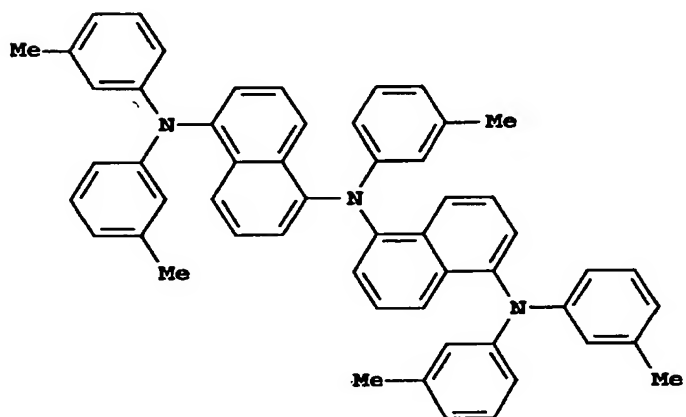
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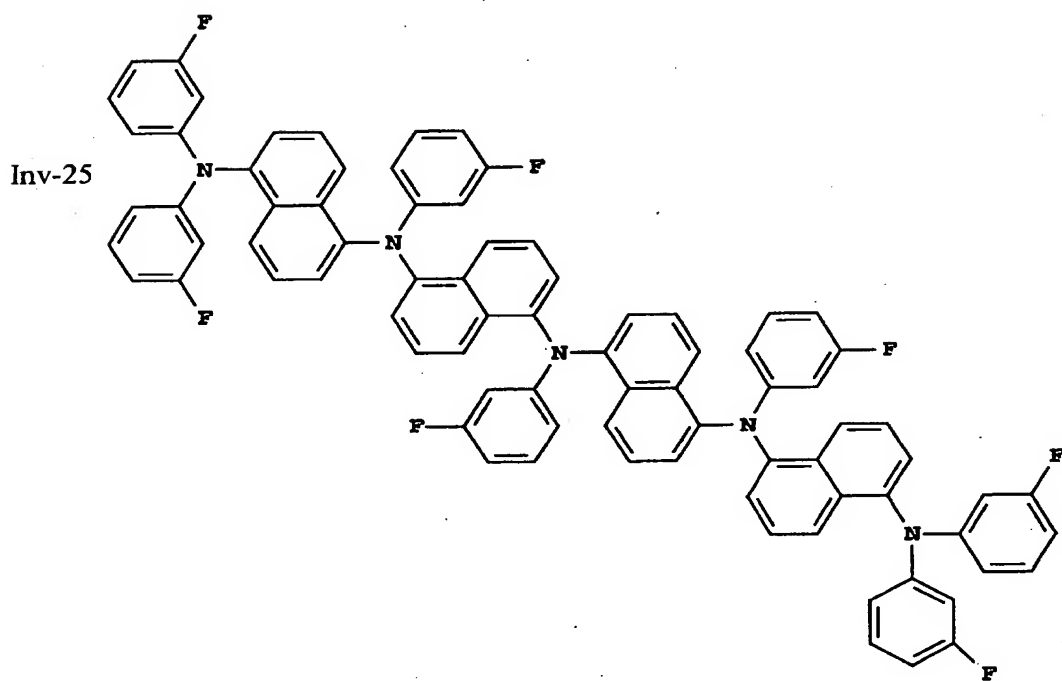
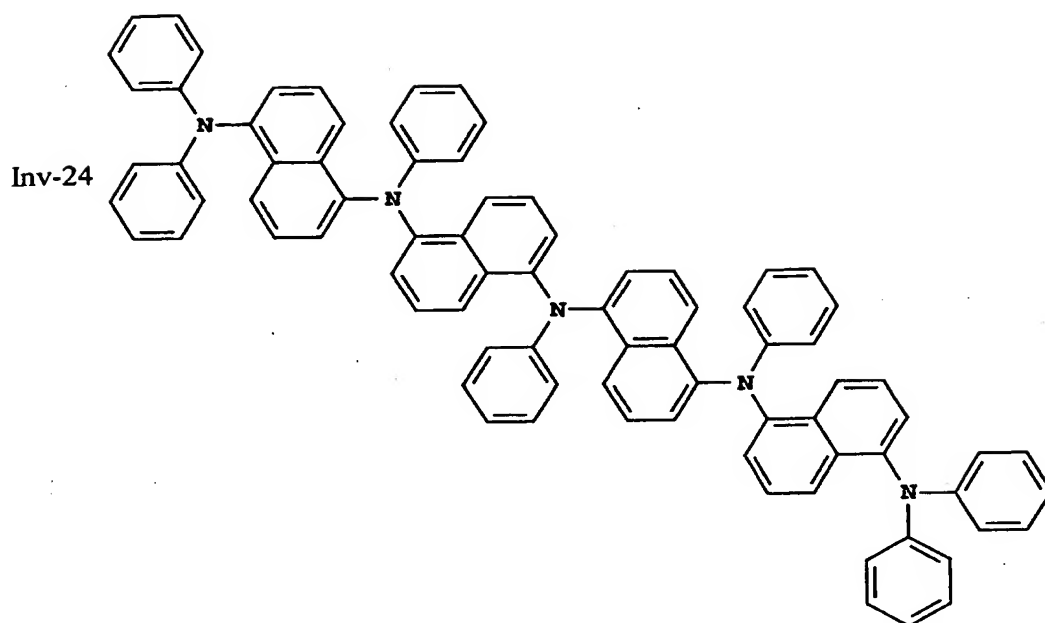


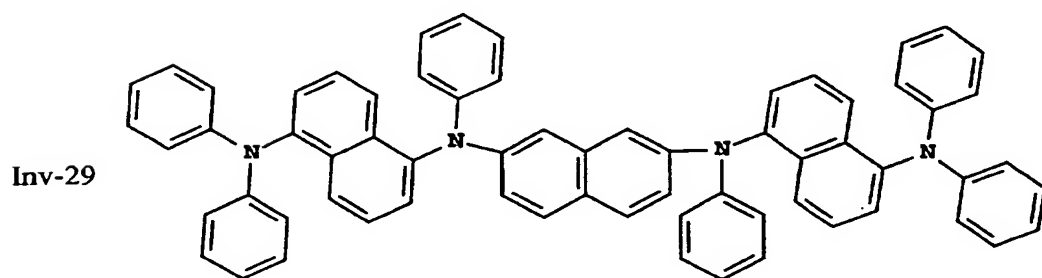
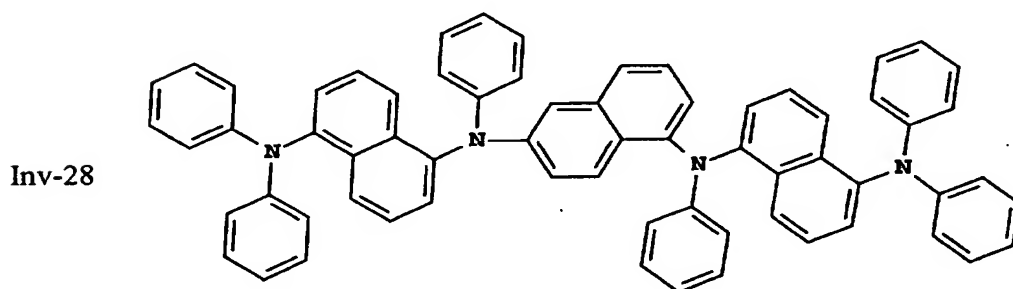
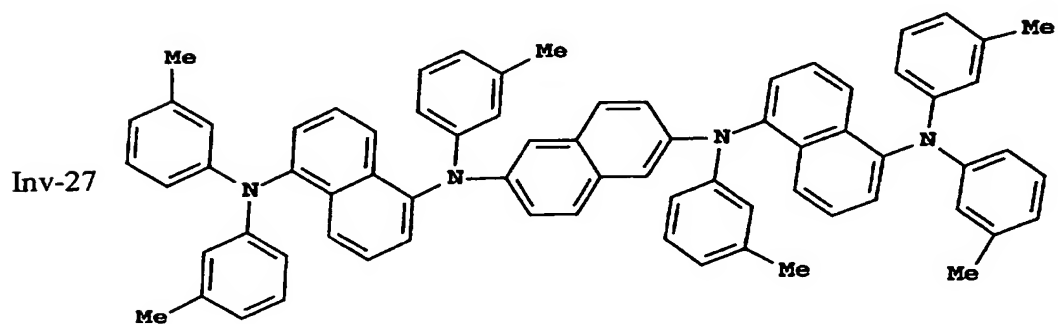
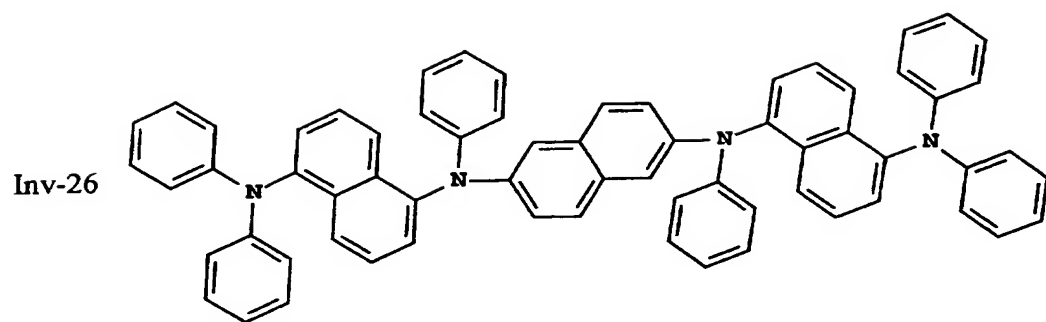
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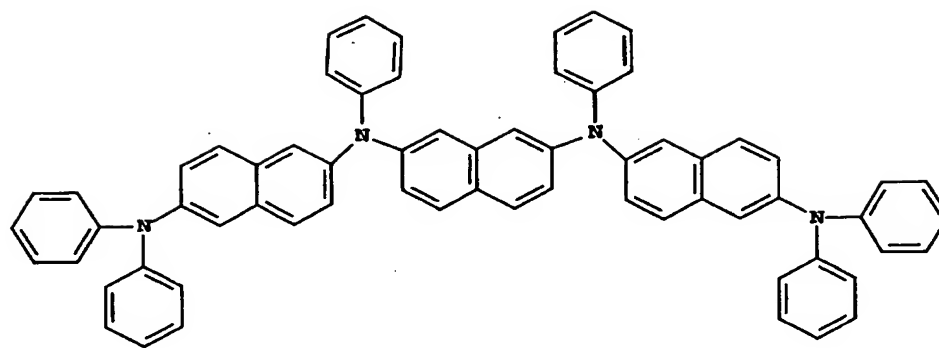
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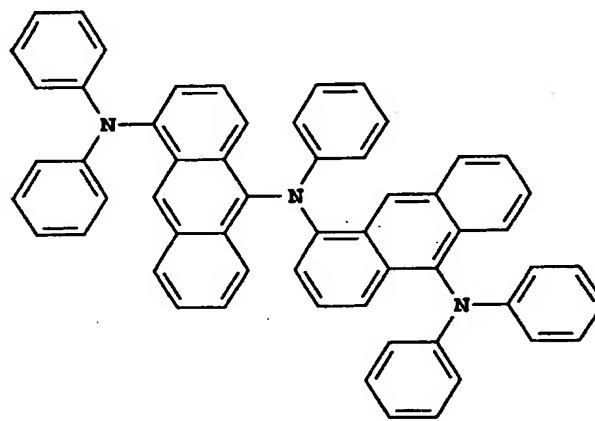




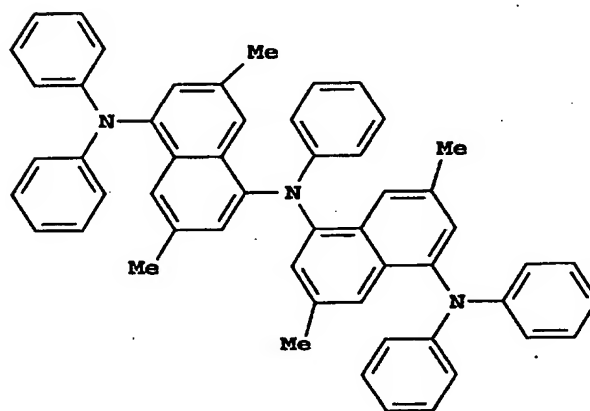
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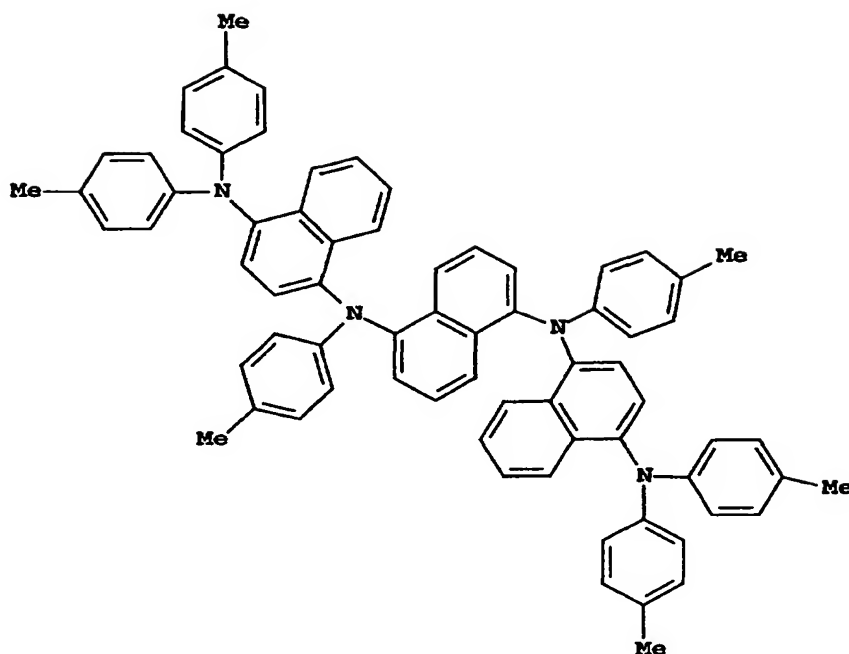
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Inv-32



Inv-33



[0023] Unless otherwise specifically stated, use of the term "substituted" or "substituent" means any group or atom other than hydrogen. Additionally, when the term "group" is used, it means that when a substituent group contains a substitutable hydrogen, it is also intended to encompass not only the substituent's unsubstituted form, but also its form further substituted with any substituent group or groups as herein mentioned, so long as the substituent does not destroy properties necessary for device utility. Suitably, a substituent group may be halogen or may be bonded to the remainder of the molecule by an atom of carbon, silicon, oxygen, nitrogen, phosphorous, or sulfur. The substituent may be, for example, halogen, such as chlorine, bromine or fluorine; nitro; hydroxyl; cyano; carboxyl; or groups which may be further substituted, such as alkyl, including straight or branched chain or cyclic alkyl, such as methyl, trifluoromethyl, ethyl, *t*-butyl, 3-(2,4-di-*t*-pentylphenoxy) propyl, and tetradecyl; alkenyl, such as ethylene, 2-butene; alkoxy, such as methoxy, ethoxy, propoxy, butoxy, 2-methoxyethoxy, *sec*-butoxy, hexyloxy, 2-ethylhexyloxy, tetradecyloxy, 2-(2,4-di-*t*-pentylphenoxy)ethoxy, and 2-dodecyloxyethoxy; aryl such as phenyl, 4-*t*-butylphenyl, 2,4,6-trimethylphenyl, naphthyl; aryloxy, such as phenoxy, 2-methylphenoxy, alpha- or beta-naphthyloxy, and 4-tolyloxy; carbonamido, such as acetamido, benzamido, butyramido, tetradecanamido, alpha-(2,4-di-*t*-pentylphenoxy)acetamido, alpha-(2,4-di-*t*-pentylphenoxy)butyramido, alpha-(3-pentadecylphenoxy)-hexanamido, alpha-(4-hydroxy-3-*t*-butylphenoxy)-tetradecanamido, 2-oxo-pyrrolidin-1-yl, 2-oxo-5-tetradecylpyrrolin-1-yl, N-methyltetradecanamido, N-succinimido, N-phthalimido, 2,5-dioxo-1-oxazolidinyl, 3-dodecyl-2,5-dioxo-1-imidazolyl, and N-acetyl-N-dodecylamino, ethoxycarbonylamino, phenoxycarbonylamino, benzyloxycarbonylamino, hexadecyloxycarbonylamino, 2,4-di-*t*-butylphenoxy carbonylamino, phenylcarbonylamino, 2,5-(di-*t*-pentylphenyl)carbonylamino, *p*-dodecylphenylcarbonylamino, *p*-tolylcarbonylamino, N-methylureido, N,N-dimethylureido, N-methyl-N-dodecylureido, N-hexadecylureido, N,N-di-octadecylureido, N,N-di-octyl-N'-ethylureido, N-phenylureido, N,N-diphenylureido, N-phenyl-N-*p*-tolylureido, N-(*m*-hexadecylphenyl)ureido, N,N-(2,5-di-*t*-pentylphenyl)-N'-ethylureido, and *t*-butylcarbonamido; sulfonamido, such as methylsulfonamido, benzenesulfonamido, *p*-tolylsulfonamido, *p*-dodecylbenzenesulfonamido, N-methyltetradecylsulfonamido, N,N-dipropylsulfamoylamino, and hexadecylsulfonamido; sulfamoyl, such as N-methylsulfamoyl, N-ethylsulfamoyl, N,N-dipropylsulfamoyl, N-hexadecylsulfamoyl, N,N-dimethylsulfamoyl; N-[3-(dodecyloxy)propyl]sulfamoyl, N-[4-(2,4-di-*t*-pentylphenoxy)butyl]sulfamoyl, N-methyl-N-tetradecylsulfamoyl, and N-dodecylsulfamoyl; carbamoyl, such as N-methylcarbamoyl, N,N-dibutylcarbamoyl, N-octadecylcarbamoyl, N-[4-(2,4-di-*t*-pentylphenoxy)butyl]carbamoyl, N-methyl-N-tetradecylcarbamoyl, and N,N-di-octylcarbamoyl; acyl, such as acetyl, (2,4-di-*t*-amylphenoxy)acetyl, phenoxycarbonyl, *p*-dodecyloxyphenoxycarbonyl methoxycarbonyl, butoxycarbonyl, tetradecyloxycarbonyl, ethoxycarbonyl, benzyloxycarbonyl, 3-pentadecyloxycarbonyl, and dodecyloxycarbonyl; sulfonyl, such as methoxysulfonyl, octyloxysulfonyl, tetradecyloxysulfonyl, 2-ethylhexyloxysulfonyl, phenoxysulfonyl, 2,4-di-*t*-pentylphenoxy sulfonyl, methylsulfonyl, octylsulfonyl, 2-ethylhexylsulfonyl, dodecylsulfonyl, hexadecylsulfonyl, phenylsulfonyl, 4-nonylphenylsulfonyl, and *p*-tolylsulfonyl; sulfonyloxy, such as dodecylsulfonyloxy, and hexadecylsulfonyloxy; sulfinyl, such as methylsulfinyl, octylsulfinyl,

2-ethylhexylsulfanyl, dodecylsulfanyl, hexadecylsulfanyl, phenylsulfanyl, 4-nonylphenylsulfanyl, and *p*-tolylsulfanyl; thio, such as ethylthio, octylthio, benzylthio, tetradecylthio, 2-(2,4-di-*t*-pentylphenoxy)ethylthio, phenylthio, 2-butoxy-5-*t*-octylphenylthio, and *p*-tolylthio; acyloxy, such as acetyloxy, benzoyloxy, octadecanoyloxy, *p*-dodecylamidobenzoyloxy, N-phenylcarbamoyloxy, N-ethylcarbamoyloxy, and cyclohexylcarbonyloxy; amine, such as phenylanilino, 2-chloro-anilino, diethylamine, dodecylamine; imino, such as 1 (N-phenylimido)ethyl, N-succinimido or 3-benzylhydantoinyl; phosphate, such as dimethylphosphate and ethylbutylphosphate; phosphite, such as diethyl and dihexylphosphite; a heterocyclic group, a heterocyclic oxy group or a heterocyclic thio group, each of which may be substituted and which contain a 3 to 7 membered heterocyclic ring composed of carbon atoms and at least one hetero atom selected from the group consisting of oxygen, nitrogen and sulfur, such as 2-furyl, 2-thienyl, 2-benzimidazolyloxy or 2-benzothiazolyl; quaternary ammonium, such as triethylammonium; and silyloxy, such as trimethylsilyloxy.

[0024] If desired, the substituents may themselves be further substituted one or more times with the described substituent groups. The particular substituents used may be selected by those skilled in the art to attain the desired properties for a specific application.

General device architecture

[0025] The present invention can be employed in most OLED device configurations. These include very simple structures comprising a single anode and cathode to more complex devices, such as passive matrix displays comprised of orthogonal arrays of anodes and cathodes to form pixels, and active-matrix displays where each pixel is controlled independently, for example, with a thin film transistor (TFT). The total combined thickness of the organic layers is preferably less than 500 nm.

[0026] There are numerous configurations of the organic layers wherein the present invention can be successfully practiced. The compound of Formula (1) can be used wherever a hole transport material is called for. A typical structure is shown in Figure 1 and is comprised of a substrate **101**, an anode layer **103**, an optional hole-injecting layer **105**, a hole-transporting layer **107**, a light-emitting layer **109**, an electron-transporting layer **111**, and a cathode layer **113**. These layers are described in detail below. Figure 2 shows a variation of this embodiment in which there are employed two hole-transporting sub-layers, **107a** and **107b**.

Substrate

[0027] The substrate **101** can either be light transmissive or opaque, depending on the intended direction of light emission. The light transmissive property is desirable for viewing the EL emission through the substrate. The transparent substrate may contain, or have built up on it, various electronic structures or circuitry (e.g., low temperature poly-silicon TFT structures) so long as a transparent region or regions remain. Transparent glass or plastic is commonly employed in such cases. For applications where the EL emission is viewed through the top electrode, the transmissive characteristic of the bottom support is immaterial, and therefore can be light transmissive, light absorbing or light reflective. Substrates for use in this case include, but are not limited to, glass, plastic, semiconductor materials, ceramics, and circuit board materials. Of course it is necessary to provide in these device configurations a light transparent top electrode. The substrate, in some cases, may actually constitute the anode or cathode

Anode

[0028] The conductive anode layer **103** is formed over the substrate and, when EL emission is viewed through the anode, should be transparent or substantially transparent to the emission of interest. Common transparent anode materials used in this invention are indium-tin oxide and tin oxide, but other metal oxides can work including, but not limited to, aluminum- or indium-doped zinc oxide, magnesium-indium oxide, and nickel-tungsten oxide. In addition to these oxides, metal nitrides, such as gallium nitride, and metal selenides, such as zinc selenide, and metal sulfides, such as zinc sulfide, can be used in layer **103**. For applications where EL emission is viewed through the top electrode, the transmissive characteristics of layer **103** are immaterial and any conductive material can be used, transparent, opaque or reflective. Example conductors for this application include, but are not limited to, gold, iridium, molybdenum, palladium, and platinum. Typical anode materials, transmissive or otherwise, have a work function of 4.1 eV or greater. Desired anode materials are commonly deposited by any suitable means such as evaporation, sputtering, chemical vapor deposition, or electrochemical means. Anodes can be patterned using well-known photolithographic processes.

Hole-Injecting Layer (HIL)

[0029] While not always necessary, it is often useful that a hole-injecting layer **105** be provided adjacent to the anode **103** and between the anode and the hole-transporting layer **107**. The hole-injecting material can serve to improve the

film formation property of subsequent organic layers and to facilitate injection of holes into the hole-transporting layer. Suitable materials for use in the hole-injecting layer include, but are not limited to, porphyrinic compounds as described in US 4,720,432, and plasma-deposited fluorocarbon polymers (CFx) as described in US 6,208,075. Alternative hole-injecting materials reportedly useful in organic EL devices are described in EP 0 891 121 A1 and EP 1,029,909 A1. It is possible to employ materials useful in the invention in addition to the foregoing materials.

Hole-Transporting Layer (HTL)

[0030] In a desirable embodiment of this invention, the hole-transporting layer 107 (or layers 107a and 107b) of the organic EL device contains at least one compound described in Formula (1). While the naphthalene compound of Formula (1) can be used alone as the HTL material, a useful embodiment is to use two HTL materials preferably where the layer 107 is divided into two regions or sub layers, 107a and 107b, as shown in Figure 2. The naphthalene compound of Formula (1) can be used in either or both layers, but it is preferred if it is at least used in layer 107a, closer to the anode.

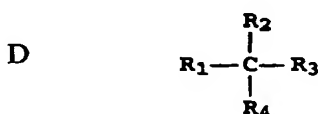
[0031] Other HTL materials described below can be used in combination with Formula (1) as a mixture in layer 107, or as a discrete material or mixture in layers 107a or 107b. One useful class of hole-transporting compounds are aromatic tertiary amines, where the latter is understood to be a compound containing at least one trivalent nitrogen atom that is bonded only to carbon atoms, at least one of which is a member of an aromatic ring. In one form the aromatic tertiary amine can be an arylamine, such as a monoarylamine, diarylamine, triarylamine, or a polymeric arylamine. Exemplary monomeric triarylaminines are illustrated by Klupfel et al. US 3,180,730. Other suitable triarylaminines substituted with one or more vinyl radicals and/or comprising at least one active hydrogen containing group are disclosed by Brantley et al US 3,567,450 and US 3,658,520.

[0032] A more preferred class of aromatic tertiary amines are those which include at least two aromatic tertiary amine moieties as described in US 4,720,432 and US 5,061,569. Such compounds include those represented by structural formula (C).



wherein Q₁ and Q₂ are independently selected aromatic tertiary amine moieties and G is a linking group such as an arylene, cycloalkylene, or alkylene group of a carbon to carbon bond. In one embodiment, at least one of Q₁ or Q₂ contains a polycyclic fused ring structure, e.g., a naphthalene. When G is an aryl group, it is conveniently a phenylene, biphenylene, or naphthalene moiety.

[0033] A useful class of triarylaminines satisfying structural formula (C) and containing two triarylamine moieties is represented by structural formula (D):



where

R₁ and R₂ each independently represents a hydrogen atom, an aryl group, or an alkyl group or R₁ and R₂ together represent the atoms completing a cycloalkyl group; and

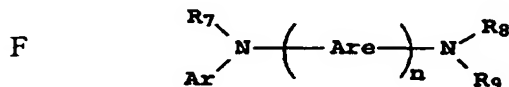
R₃ and R₄ each independently represents an aryl group, which is in turn substituted with a diaryl substituted amino group, as indicated by structural formula (E):



wherein R₅ and R₆ are independently selected aryl groups. In one embodiment, at least one of R₅ or R₆ contains a

polycyclic fused ring structure, e.g., a naphthalene.

[0034] Another class of aromatic tertiary amines are the tetraaryldiamines. Desirable tetraaryldiamines include two diarylamino groups, such as indicated by formula (E), linked through an arylene group. Useful tetraaryldiamines include those represented by formula (F).



wherein

each Are is an independently selected arylene group, such as a phenylene or anthracene moiety;

n is an integer of from 1 to 4; and

Ar, R₇, R₈, and R₉ are independently selected aryl groups.

In a typical embodiment, at least one of Ar, R₇, R₈, and R₉ is a polycyclic fused ring structure, e.g., a naphthalene

[0035] The various alkyl, alkylene, aryl, and arylene moieties of the foregoing structural formulae (C), (D), (E), (F), can each in turn be substituted. Typical substituents include alkyl groups, alkoxy groups, aryl groups, aryloxy groups, and halogen such as fluoride, chloride, and bromide. The various alkyl and alkylene moieties typically contain from 1 to 6 carbon atoms. The cycloalkyl moieties can contain from 3 to 10 carbon atoms, but typically contain five, six, or seven ring carbon atoms--e.g., cyclopentyl, cyclohexyl, and cycloheptyl ring structures. The aryl and arylene moieties are usually phenyl and phenylene moieties.

[0036] Illustrative of useful aromatic tertiary amines are the following:

1,1-Bis(4-di-*p*-tolylaminophenyl)cyclohexane
 1,1-Bis(4-di-*p*-tolylaminophenyl)-4-phenylcyclohexane
 4,4'-Bis(diphenylamino)quadriphenyl
 Bis(4-dimethylamino-2-methylphenyl)-phenylmethane
 N,N,N-Tri(*p*-tolyl)amine
 4-(di-*p*-tolylamino)-4'-[4(di-*p*-tolylamino)-styryl]stilbene
 N,N,N',N'-Tetra-*p*-tolyl-4,4'-diaminobiphenyl
 N,N,N',N'-Tetraphenyl-4,4'-diaminobiphenyl
 N-Phenylcarbazole
 Poly(N-vinylcarbazole), and
 N,N'-di-1-naphthalenyl-N,N'-diphenyl-4,4'-diaminobiphenyl.
 4,4'-Bis[N-(1-naphthyl)-N-phenylamino]biphenyl
 4,4'-Bis[N-(1-naphthyl)-N-phenylamino]*p*-terphenyl
 4,4'-Bis[N-(2-naphthyl)-N-phenylamino]biphenyl "NPB"
 4,4'-Bis[N-(3-acenaphthenyl)-N-phenylamino]biphenyl
 1,5-Bis[N-(1-naphthyl)-N-phenylamino]naphthalene
 4,4'-Bis[N-(9-anthryl)-N-phenylamino]biphenyl
 4,4'-Bis[N-(1-anthryl)-N-phenylamino]-*p*-terphenyl
 4,4'-Bis[N-(2-phenanthryl)-N-phenylamino]biphenyl
 4,4'-Bis[N-(8-fluoranthryl)-N-phenylamino]biphenyl
 4,4'-Bis[N-(2-pyrenyl)-N-phenylamino]biphenyl
 4,4'-Bis[N-(2-naphthacenyl)-N-phenylamino]biphenyl
 4,4'-Bis[N-(2-perylenyl)-N-phenylamino]biphenyl
 4,4'-Bis[N-(1-coronenyl)-N-phenylamino]biphenyl
 2,6-Bis(di-*p*-tolylamino)naphthalene
 2,6-Bis[di-(1-naphthyl)amino]naphthalene
 2,6-Bis[N-(1-naphthyl)-N-(2-naphthyl)amino]naphthalene
 N,N,N',N'-Tetra(2-naphthyl)-4,4'-diamino-*p*-terphenyl
 4,4'-Bis[N-phenyl-N-[4-(1-naphthyl)-phenyl]amino]biphenyl
 4,4'-Bis[N-phenyl-N-(2-pyrenyl)amino]biphenyl
 2,6-Bis[N,N-di(2-naphthyl)amine]fluorene
 1,5-Bis[N-(1-naphthyl)-N-phenylamino]naphthalene
 [1,1'-Biphenyl]-4,4'-diamine, N,N'-di-1-naphthalenyl-N,N'-di-2-naphthalenyl-

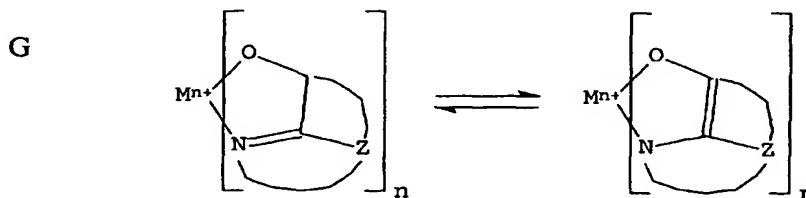
Light-Emitting Layer (LEL)

[0037] As more fully described in US 4,769,292 and 5,935,721, the light-emitting layer (LEL) 109 of the organic EL element comprises a luminescent or fluorescent material where electroluminescence is produced as a result of electron-hole pair recombination in this region. The light-emitting layer can be comprised of a single material, but more commonly consists of a host material doped with a guest compound or compounds where light emission comes primarily from the dopant and can be of any color. The host materials in the light-emitting layer can be an electron-transporting material, as defined below, a hole-transporting material, as defined above, a mixture of hole- and electron-transporting materials, or another material or mixture that supports hole-electron recombination. The dopant is usually chosen from highly fluorescent dyes, but phosphorescent compounds, e.g., transition metal complexes as described in WO 98/55561, WO 00/18851, WO 00/57676, and WO 00/70655 are also useful. Dopants are typically coated as 0.01 to 10 % by weight into the host material.

[0038] An important relationship for choosing a dye as a dopant is a comparison of the bandgap potential which is defined as the energy difference between the highest occupied molecular orbital and the lowest unoccupied molecular orbital of the molecule. For efficient energy transfer from the host to the dopant molecule, a necessary condition is that the band gap of the dopant is smaller than that of the host material.

[0039] Host and emitting molecules known to be of use include, but are not limited to, those disclosed in US 4,768,292, US 5,141,671, US 5,150,006, US 5,151,629, US 5,405,709, US 5,484,922, US 5,593,788, US 5,645,948, US 5,683,823, US 5,755,999, US 5,928,802, US 5,935,720, US 5,935,721, and US 6,020,078.

[0040] Metal complexes of 8-hydroxyquinoline and similar derivatives (Formula G) constitute one class of useful host compounds capable of supporting electroluminescence, and are particularly suitable for light emission of wavelengths longer than 500 nm, e.g., green, yellow, orange, and red.



wherein

M represents a metal;

n is an integer of from 1 to 3; and

Z independently in each occurrence represents the atoms completing a nucleus having at least two fused aromatic rings.

[0041] From the foregoing it is apparent that the metal can be monovalent, divalent, or trivalent metal. The metal can, for example, be an alkali metal, such as lithium, sodium, or potassium; an alkaline earth metal, such as magnesium or calcium; or an earth metal, such as boron or aluminum. Generally any monovalent, divalent, or trivalent metal known to be a useful chelating metal can be employed.

[0042] Z completes a heterocyclic nucleus containing at least two fused aromatic rings, at least one of which is an azole or azine ring. Additional rings, including both aliphatic and aromatic rings, can be fused with the two required rings, if required. To avoid adding molecular bulk without improving on function the number of ring atoms is usually maintained at 18 or less.

[0043] Illustrative of useful chelated oxinoid compounds are the following:

CO-1: Aluminum trisoxine [alias, tris(8-quinolinolato)aluminum(III)]

CO-2: Magnesium bisoxine [alias, bis(8-quinolinolato)magnesium(II)]

CO-3: Bis[benzo{f}-8-quinolinolato]zinc (II)

CO-4: Bis(2-methyl-8-quinolinolato)aluminum(III)-μ-oxo-bis(2-methyl-8-quinolinolato) aluminum(III)

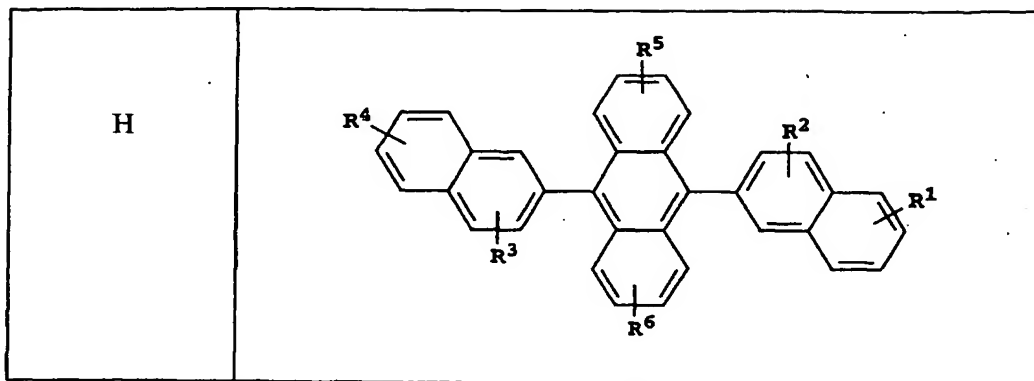
CO-5: Indium trisoxine [alias, tris(8-quinolinolato)indium]

CO-6: Aluminum tris(5-methyloxine) [alias, tris(5-methyl-8-quinolinolato) aluminum(III)]

CO-7: Lithium oxine [alias, (8-quinolinolato)lithium(I)]

[0044] Derivatives of 9,10-di-(2-naphthyl)anthracene (Formula H) constitute one class of useful hosts capable of supporting electroluminescence, and are particularly suitable for light emission of wavelengths longer than 400 nm, e.

g., blue, green, yellow, orange or red.



wherein: R¹, R², R³, R⁴, R⁵, and R⁶ represent one or more substituents on each ring where each substituent is individually selected from the following groups:

Group 1: hydrogen, or alkyl of from 1 to 24 carbon atoms;

Group 2: aryl or substituted aryl of from 5 to 20 carbon atoms;

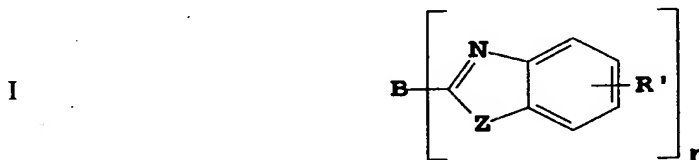
Group 3: carbon atoms from 4 to 24 necessary to complete a fused aromatic ring of anthracenyl; pyrenyl, or perylenyl;

Group 4: heteroaryl or substituted heteroaryl of from 5 to 24 carbon atoms as necessary to complete a fused heteroaromatic ring of furyl, thienyl, pyridyl, quinoliny or other heterocyclic systems;

Group 5: alkoxyamino, alkylamino, or arylamino of from 1 to 24 carbon atoms; and

Group 6: fluorine, chlorine, bromine or cyano.

[0045] Benzazole derivatives (Formula (I)) constitute another class of useful hosts capable of supporting electroluminescence, and are particularly suitable for light emission of wavelengths longer than 400 nm, e.g., blue, green, yellow, orange or red.



Where:

N is an integer of 3 to 8;

Z is O, NR or S; and

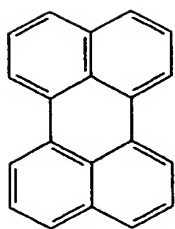
R and R' are individually hydrogen; alkyl of from 1 to 24 carbon atoms, for example, propyl, t-butyl, heptyl, and the like; aryl or hetero-atom substituted aryl of from 5 to 20 carbon atoms for example phenyl and naphthyl, furyl, thienyl, pyridyl, quinoliny and other heterocyclic systems; or halo such as chloro, fluoro; or atoms necessary to complete a fused aromatic ring;

B is a linkage unit consisting of alkyl, aryl, substituted alkyl, or substituted aryl, which conjugately or unconjugately connects the multiple benzazoles together.

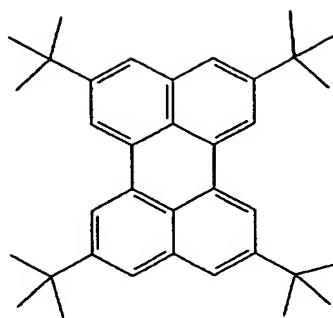
[0046] An example of a useful benzazole is 2, 2', 2''-(1,3,5-phenylene)tris[1-phenyl-1H-benzimidazole].

[0047] Desirable fluorescent dopants include derivatives of anthracene, tetracene, xanthene, perylene, rubrene, coumarin, rhodamine, quinacridone, dicyanomethylenepyran compounds, thiopyran compounds, polymethine compounds, pyrilium and thiapyrilium compounds, and carbostyryl compounds. Illustrative examples of useful luminescent dopants include, but are not limited to, the following:

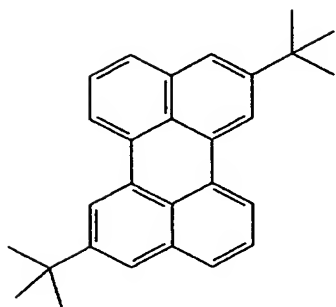
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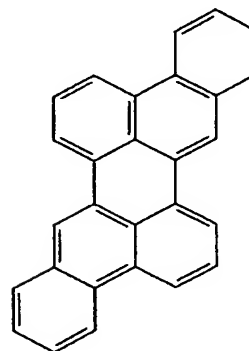
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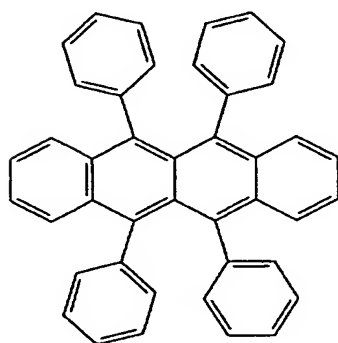


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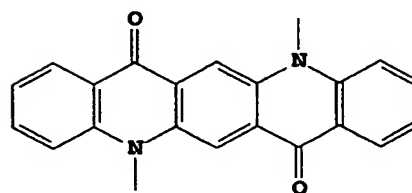


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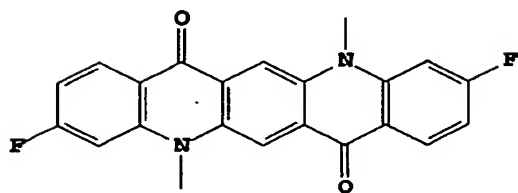


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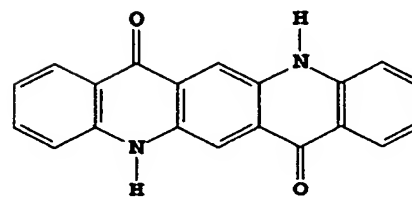


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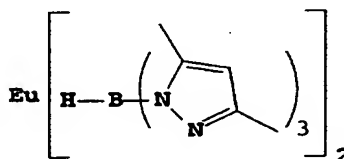
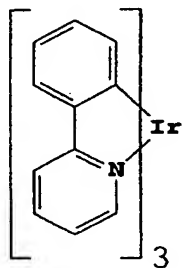
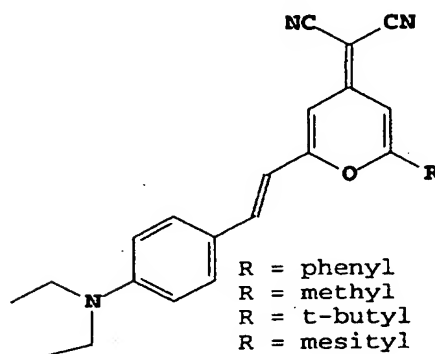
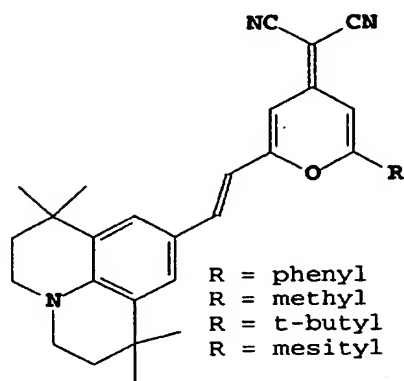
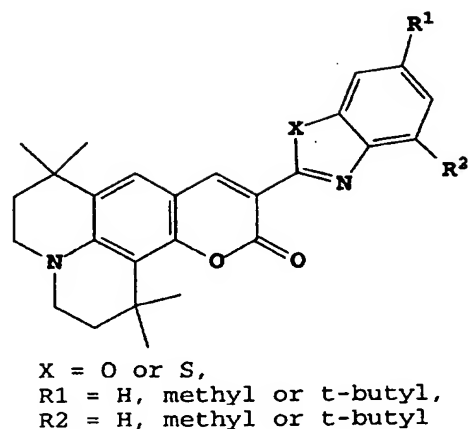
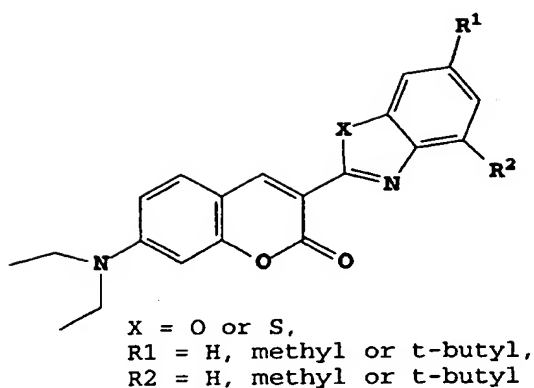
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Electron-Transporting Layer (ETL)

[0048] Preferred thin film-forming materials for use in forming the electron-transporting layer 111 of the organic EL devices of this invention are metal chelated oxinoid compounds, including chelates of oxine itself (also commonly referred to as 8-quinolinol or 8-hydroxyquinoline). Such compounds help to inject and transport electrons and exhibit both high levels of performance and are readily fabricated in the form of thin films. Exemplary of contemplated oxinoid compounds are those satisfying structural formula (G), previously described.

[0049] Other electron-transporting materials include various butadiene derivatives as disclosed in US 4,356,429 and various heterocyclic optical brighteners as described in US 4,539,507. Benzazoles satisfying structural formula (I) are also useful electron transporting materials.

[0050] In some instances, layers 109 and 111 can optionally be collapsed into a single layer that serves the function of supporting both light emission and electron transportation.

Cathode

[0051] When light emission is through the anode, the cathode layer 113 used in this invention can be comprised of nearly any conductive material. Desirable materials have good film-forming properties to ensure good contact with the underlying organic layer, promote electron injection at low voltage, and have good stability. Useful cathode materials often contain a low work function metal (< 4.0 eV) or metal alloy. One preferred cathode material is comprised of a Mg: Ag alloy wherein the percentage of silver is in the range of 1 to 20 %, as described in US 4,885,221. Another suitable class of cathode materials includes bilayers comprised of a thin layer of a low work function metal or metal salt capped with a thicker layer of conductive metal. One such cathode is comprised of a thin layer of LiF followed by a thicker layer of Al as described in US 5,677,572. Other useful cathode materials include, but are not limited to, those disclosed in US 5,059,861, US 5,059,862, and US 6,140,763.

[0052] When light emission is viewed through the cathode, the cathode must be transparent or nearly transparent. For such applications, metals must be thin or one must use transparent conductive oxides, or a combination of these materials. Optically transparent cathodes have been described in more detail in US 5,776,623. Cathode materials can be deposited by evaporation, sputtering, or chemical vapor deposition. When needed, patterning can be achieved through many well known methods including, but not limited to, through-mask deposition, integral shadow masking as described in US 5,276,380 and EP 0 732 868, laser ablation, and selective chemical vapor deposition.

Deposition of organic layers

[0053] The organic materials mentioned above are suitably deposited through sublimation, but can be deposited from a solvent with an optional binder to improve film formation. If the material is a polymer, solvent deposition is usually preferred. The material to be deposited by sublimation can be vaporized from a sublimator "boat" often comprised of a tantalum material, e.g., as described in US 6,237,529, or can be first coated onto a donor sheet and then sublimed in closer proximity to the substrate. Layers with a mixture of materials can utilize separate sublimator boats or the materials can be pre-mixed and coated from a single boat or donor sheet. Patterned deposition can be achieved using shadow masks, integral shadow masks (US 5,294,870), spatially defined thermal dye transfer from a donor sheet (US 5,851,709 and US 6,066,357) and inkjet method (US 6,066,357).

Encapsulation

[0054] Most OLED devices are sensitive to moisture and/or oxygen so they are commonly sealed in an inert atmosphere such as nitrogen or argon, along with a desiccant such as alumina, bauxite, calcium sulfate, clays, silica gel, zeolites, alkaline metal oxides, alkaline earth metal oxides, sulfates, or metal halides and perchlorates. Methods for encapsulation and desiccation include, but are not limited to, those described in US 6,226,890.

EXAMPLES

[0055] The invention and its advantages are further illustrated by the specific examples which follow.

SynthesisExample 1 -Preparation of N,N'-Diphenyl-1,5-diaminonaphthalene:

[0056] 1,5-Diaminonaphthalene (2.5 g, 15.8 mmol) was combined with iodobenzene (7.1 g, 34.8 mmol), palladium diacetate (100 mg, 0.5 mmol), tri-*t*-butylphosphine (0.3 mL), sodium *t*-butoxide (4.0g, 41.6 mmol), and toluene (60 mL). The mixture was heated at 110 °C with magnetic stirring under a nitrogen atmosphere. After 2 h, an additional amount of palladium diacetate (100 mg, 0.5 mmol) was added. After heating for another 2 h, the heat was removed. After cooling to room temperature, the solid present was collected and washed with acetone. The solid was combined with hot acetone (150 mL) and the solution was filtered. The product precipitated on cooling (1.3g, 26%).

[0057] Preparation of Compound 1 (Inv-1): N,N'-Diphenyl-1,5-diaminonaphthalene (1.5 g, 4.8 mmol), 4-bromo-N,N-di-*p*-tolylaniline (3.4 g, 9.7 mmol), palladium diacetate (150 mg, 0.7 mmol), tri-*t*-butylphosphine (0.6 mL), sodium *t*-butoxide (1.1 g, 11.5 mmol), and xylene (75 mL) were combined and heated to 130 °C for 2 h with magnetic stirring under a nitrogen atmosphere. The heat was removed and after cooling to room temperature the reaction mixture was filtered. The filtrate was evaporated and the resulting solid was combined with ethyl acetate (75 mL) and the mixture was heated to reflux and stirred for 45 min. After cooling, the product was collected (3.3 g, 80% yield). A portion of the product (1.65 g) was sublimed twice (335-340 °C, 6×10^{-1} torr) affording 0.66 g of an amorphous solid. The Tg of this material was 124 °C.

[0058] Example 2 - Preparation of Compound 2 (Inv-2): N,N'-Diphenyl-1,5-diaminonaphthalene (1.55 g, 5.0 mmol), 4-bromo-N,N-diphenylaniline (3.24 g, 10.0 mmol), palladium diacetate (150 mg, 0.7 mmol), tri-*t*-butylphosphine (0.6 mL), sodium *t*-butoxide (1.1 g, 11.5 mmol), and xylene (75 mL) were combined and heated to 130 °C for 2.5 h with magnetic stirring under a nitrogen atmosphere. The heat was removed and after cooling to room temperature the reaction mixture was filtered. The filtrate was evaporated and the resulting solid was purified by column chromatography (silica gel, 30% dichloromethane, 70% heptane) and sublimed (355 °C, 6×10^{-1} torr) affording 1.6 g of product (40 % yield). The Tg of this material was 119 °C.

Example 3 - EL Device Fabrication and Performance

[0059] A series of EL devices satisfying the requirements of the invention were constructed in the following manner:

[0060] A glass substrate coated with an 42 nm layer of indium-tin oxide (ITO) as the anode was sequentially ultrasonicated in a commercial detergent, rinsed in deionized water, degreased in toluene vapor and exposed to oxygen plasma for about 1 min.

a) Over the ITO was deposited a 1 nm fluorocarbon hole-injecting layer (CFx) by plasma-assisted deposition of CHF_3 .

b) A first layer of Compound 1 (Inv-1, see Table 1 for layer thickness) was then deposited over the CFx by evaporation from a tantalum boat.

c) A hole-transporting layer of N,N'-di-1-naphthalenyl-N,N'-diphenyl-4, 4'-diaminobiphenyl (NPB, see Table 1 for layer thickness), was then evaporated from a tantalum boat.

d) A 75 nm light-emitting/electron transport layer of tris(8-quinolinolato)aluminum (III) (AlQ_3) was then deposited onto the hole-transporting layer. This material was also evaporated from a tantalum boat.

e) On top of the AlQ_3 layer was deposited a 220 nm cathode formed of a 10:1 atomic ratio of Mg and Ag.

[0061] A comparison device was prepared omitting layer b) and containing an overall hole-transporting layer thickness substantially the same as the other examples.

[0062] The cells thus formed were tested for luminance with a constant current of 20 mA/cm² and the results are reported in Table I. It can be seen from Table I that the compounds useful in the invention, when incorporated into EL cells, give an increase in luminance of 30 - 40% compared to the check comparison.

Table I.

Evaluation Results for Compound 1 (Inv-1).					
Example	Type	Compound 1 (Inv-1) Layer b) Thickness (nm)	Compound NPB Layer c) Thickness (nm)	Cell Luminance (candela/m ²)	Relative Luminance (%)
3-1	Comparison	0.0	75.0	512	100
3-2	Invention	5.2	70.3	682	133
3-3	Invention	20.1	55.0	668	130
3-4	Invention	55.0	20.0	716	140
3-5	Invention	70.0	5.2	718	140
3-6	Invention	75.1	0.0	377	74

[0063] It is noted that Sample 3-6 provides useful luminance although not as good as the previously known NPB compound. Moreover, when used in combination with the NPB compound, superior results are obtained compared to the use of NPB or the naphthalene compound alone.

Example 4 - EL Device Fabrication and Performance using Compound 2 (Inv-2)

[0064] A series of EL devices were prepared as described in Example 3, except the ITO thickness was 85nm and CFx plasma treatment was omitted. Compound 2 (Inv-2) in layer b) was used as the hole-injecting material and the thickness of layers b) and c) is given in Table II. The cells thus formed were tested for luminance with a constant current of 20 mA/cm² and the results are also reported in Table II.

Table II.

Evaluation Results for Compound 2 (Inv-2).					
Example	Type	Compound 2 (Inv-2) Layer b) Thickness (nm)	Compound NPB Layer c) Thickness (nm)	Cell Luminance (candela/m ²)	Relative Luminance
4-1	Comparison	0.0	75.3	675	100
4-2	Invention	5.0	70.1	828	123
4-3	Invention	70.2	5.3	851	126

[0065] The addition of the naphthalene compound provided improved luminance.

Example 5 - EL Device Fabrication and Performance Using a Dopant

[0066] A series of EL devices were prepared as described in Example 4. Compound 2 (Inv-2) was used as the hole injecting material and the thickness of the hole injecting layer is given in Table III. A green fluorescent dopant, D-1, was co-deposited in the AlQ₃ layer (d) at a level of 1%. The cells thus formed were tested for luminance with a constant current of 20 mA/cm² and the results are also reported in Table III. The EL color of the cells was green with average 1931 CIE color coordinates of x=0.328 and y=0.627. The EL spectra indicate that the green EL emission originates from the dopant in the AlQ₃ layer. Cells containing Compound 2 (Inv-2) gave improved luminance.

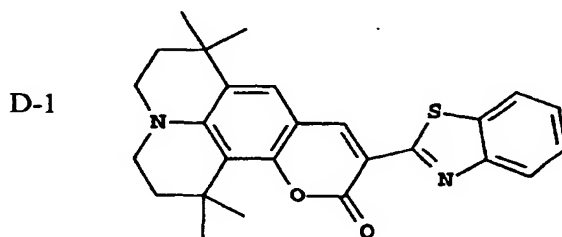


Table III.

Evaluation Results for Compound 2 (Inv-2) and a Green Dopant.					
Example	Type	Compound 2 (Inv-2) Layer Thickness (nm)	Compound NPB Layer Thickness (nm)	Cell Luminance (candela/m ²)	Relative Luminance
5-1	Comparison	0.0	75.1	1799	100
5-2	Invention	5.0	70.1	2222	123
5-3	Invention	70.0	5.0	2359	131

Example 6 -Preparation of N,N,N'-Triphenyl-1,5-diaminonaphthalene:

[0067] 1,5-Diaminonaphthalene (16.0 g, 0.101 mol) was combined with bromobenzene (47.1 g, 0.300 mol), palladium diacetate (1.2 g, 0.004 mol), tri-*t*-butylphosphine (4 mL), sodium *t*-butoxide (24.0g, 0.26 mol), and xylene (400 mL). The mixture was heated at 140 °C with magnetic stirring under a nitrogen atmosphere. After 15 h, an additional amount of palladium diacetate (0.100 g, 0.0004 mol) was added. After heating for another 6 h, an additional amount of palladium diacetate (0.100 g, 0.0004 mol) was added. After heating for another 15 h the heat was removed. After cooling to room temperature, the solid present was filtered off and the filtrate was purified by column chromatography. This afforded 6.0 g (15% yield) of N,N,N'-triphenyl-1,5-diaminonaphthalene.

[0068] Preparation of Compound Inv-18: N,N,N'-Triphenyl-1,5-diaminonaphthalene (1.0 g, 2.5 mmol), 1,5-dibrom-

onaphthalene (0.4 g, 1.4 mmol), palladium diacetate (100 mg, 0.4 mmol), tri-*t*-butylphosphine (0.4 mL), sodium *t*-butoxide (0.3 g, 3.3 mmol), and toluene (30 mL) were combined and heated to 110 °C for 6 h with magnetic stirring under a nitrogen atmosphere. The solid formed was collected and washed with toluene and dried. The product was sublimed twice (390 °C, 0.25 torr) affording 0.620 g (53% yield) of an amorphous solid, mass spectrum: $m/e = 896$ (M-1).

Example 7 - EL Device Fabrication and Performance

[0069] A series of EL devices satisfying the requirements of the invention were constructed in the following manner:

[0070] A glass substrate coated with an 42 nm layer of indium-tin oxide (ITO) as the anode was sequentially ultrasonicated in a commercial detergent, rinsed in deionized water, degreased in toluene vapor and exposed to oxygen plasma for about 1 min.

a) Over the ITO was deposited a 1 nm fluorocarbon hole-injecting layer (CFx) by plasma-assisted deposition of CHF_3 .

b) A first layer of Inv-18 (see Table IV for layer thickness) was then deposited over the CFx by evaporation from a tantalum boat.

c) A hole-transporting layer of N,N'-di-1-naphthalenyl-N,N'-diphenyl-4, 4'-diaminobiphenyl (NPB, see Table IV for layer thickness), was then evaporated from a tantalum boat.

d) A 75 nm light-emitting/electron transport layer of tris(8-quinolinolato)aluminum (III) (AlQ_3) was then deposited onto the hole-transporting layer. This material was also evaporated from a tantalum boat.

e) On top of the AlQ_3 layer was deposited a 220 nm cathode formed of a 10:1 atomic ratio of Mg and Ag.

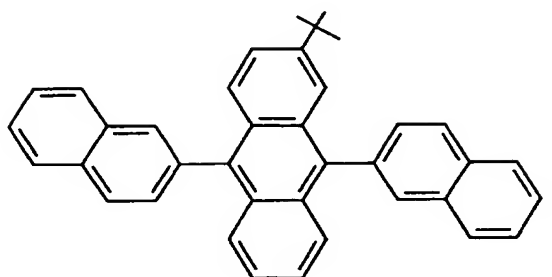
[0071] A comparison device was prepared omitting layer b) and containing an overall hole-transporting layer thickness substantially the same as the other examples.

[0072] The cells thus formed were tested for luminance with a constant current of 20 mA/cm² and the results are reported in Table IV. It can be seen from Table IV that the compounds useful in the invention, when incorporated into EL cells, give an increase in luminance compared to the check comparison.

Table IV.

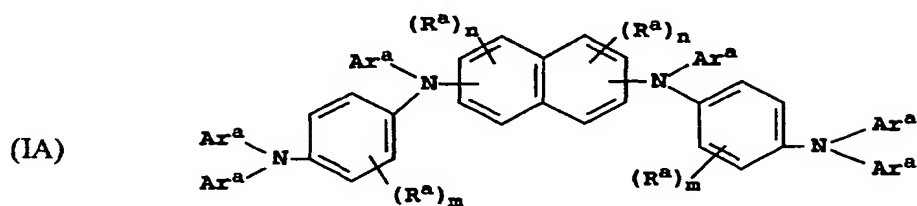
Evaluation Results for Compound Inv-18.					
Example	Type	Compound Inv-18 (Layer b) Thickness (nm)	Compound NPB (Layer c) Thickness (nm)	Cell Luminance (candela/m ²)	Relative Luminance (%)
3-1	Comparison	0.0	75.0	534	100
3-2	Invention	5.2	70.3	550	103
3-3	Invention	20.1	55.0	702	132
3-4	Invention	55.0	20.0	784	147
3-5	Invention	70.0	5.2	784	147
3-6	Invention	75.1	0.0	663	124

[0073] Embodiments of the invention include the device wherein: m is 0 or 1 or 2;
at least one R^a is a methyl group;
the LEL contains tris(8-quinolinolato)aluminum (III) (AlQ_3);
the LEL contains a compound having the formula:



;

the naphthalene compound is represented by formula (1A):



wherein

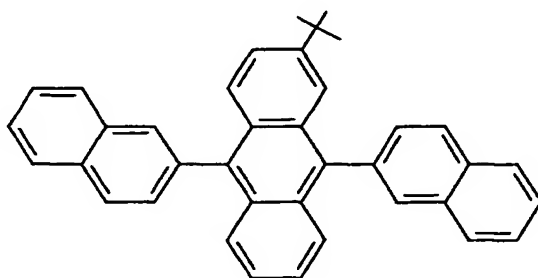
each Ar^a , R^a , and n are as defined in claim 1 and each m is independently 0-4;

the naphthalene compound is contained in a layer that is not adjacent to the LEL;

the compound of formula C is contained in the layer adjacent to the LEL;

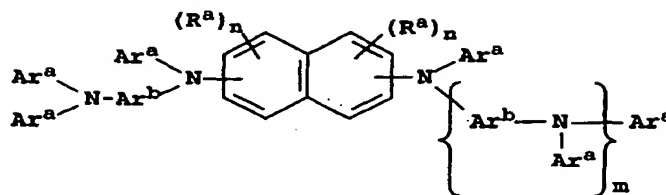
the second compound is 4,4'-Bis[N-(2-naphthyl)-N-phenylamino]biphenyl or [1,1'-Biphenyl]-4,4'-diamine, N,N'-di-1-naphthalenyl-N,N'-di-2-naphthalenyl-;

the LEL the compound tris(8-quinolinolato) aluminum (III) or a compound represented by the formula:



[0074] Embodiments also include a naphthalene compound represented by formula (1):

(1)



wherein

m is 0, 1 or 2;

each R^a is an independently selected substituent and each n is independently 0 to 3;

each Ar^a is an independently selected aromatic group; and

each Ar^b is an independently selected carbocyclic aromatic group;

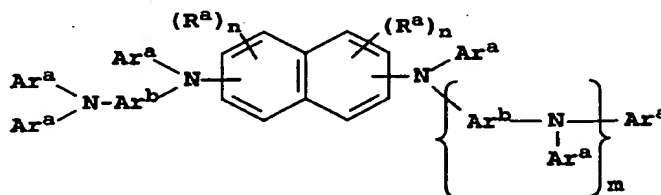
provided that two ring substituents may join to form a ring.

and a static or motion imaging device incorporating the device of the invention.

Claims

1. A multilayer electroluminescent device comprising a cathode, an anode, a light emitting layer (LEL) and a layer disposed between the cathode and anode containing a naphthalene compound represented by formula (1):

(1)



wherein

m is 0, 1 or 2;

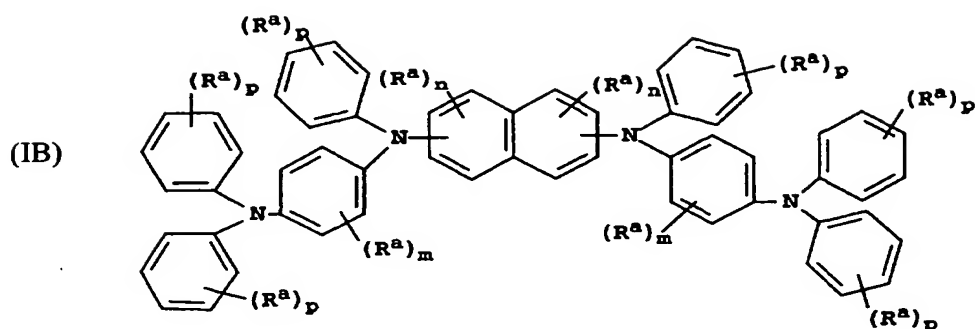
each R^a is an independently selected substituent and each n is independently 0 to 3;

each Ar^a is an independently selected aromatic group; and

each Ar^b is an independently selected carbocyclic aromatic group;

provided that two ring substituents may join to form a ring.

2. The device of claim 1 wherein the naphthalene compound is a 1,5-diamino compound.
3. The device of claim 1 wherein the naphthalene compound is a 2,6 diamino compound.
4. The device of any one of claims 1-3 wherein at least one R^a group is an alkyl or aryl group.
5. The device of any one of claims 1-4 wherein at least one Ar^a is a phenyl or heteroaromatic group.
6. The device of any one of claims 1-5 wherein at least one Ar^b is a para-substituted phenyl group.
7. The device of any one of claims 1-6 wherein the LEL contains a metal complex of a quinoline derivative.
8. The device of any one of claims 1-7 wherein the naphthalene compound is represented by formula (1B):



wherein
each R^a , m , and n are as defined in claim 1 and each p is independently 0-5.

9. The device of any one of claims 1-8 wherein the naphthalene compound is contained in a layer that is adjacent to the anode.
10. The device of any one of claims 1-8 wherein the naphthalene compound is contained in a layer that is not adjacent to the anode.
11. The device of any one of claims 1-10 wherein the naphthalene compound functions to improve hole-transporting and there is present in a layer between the anode and LEL a second compound that functions to improve hole transporting.
12. The device of claim 11 wherein one of the second compounds is represented by structural formula (C):



wherein Q_1 and Q_2 are independently selected aromatic tertiary amine moieties and G is a linking group or a bond.

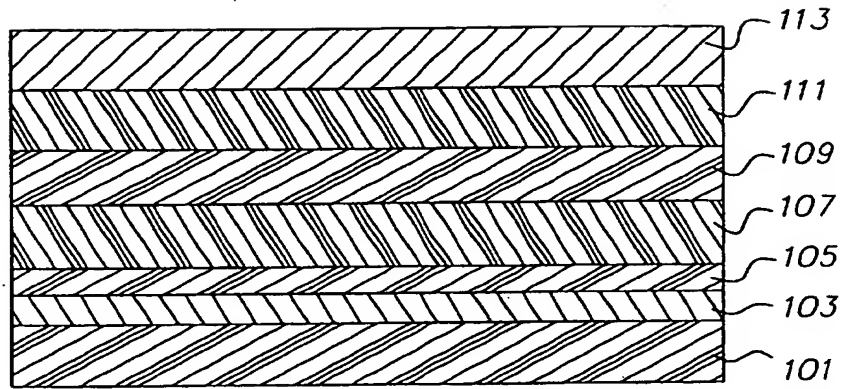


FIG. 1

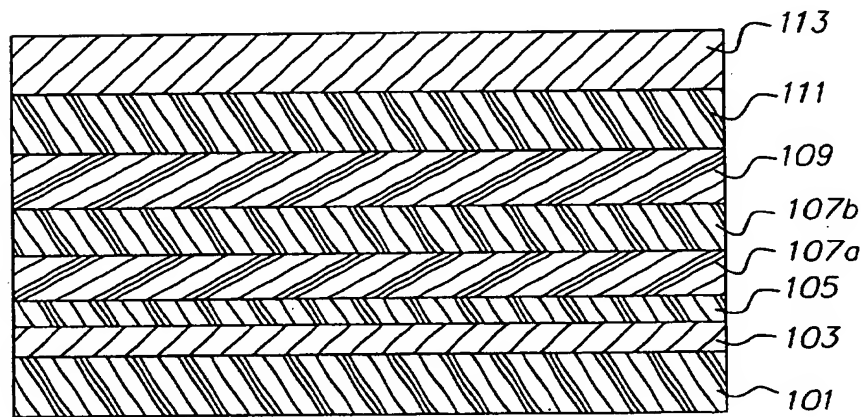


FIG. 2

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